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ENDF-201

ENDF/B SUMMARY DOCUMENTATION

Assembled by O. Ozer & D. Garber

May 1973

NATIONAL NEUTRON CROSS SECTION CENTER

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INTRODUCTION

The purpose of this publication is to provide a localized source of descriptions for the evaluations contained in the ENDF/B Library.

The summary documentation presented in this volume is intended to be a more detailed description than the (File 1) comments contained in the computer readable data files, but not as detailed as the formal reports describing each ENDF/B evaluation. (A list of the published formal reports is given in the table of contents.)

The summary documentations were written by the CSEWG (Cross Section Evaluation Working Group) evaluators and compiled by NNCSC (National Neutron Cross Section Center). When assembling the information for this volume, a minimum amount of editing was unavoidable. This editing primarily consisted of removing computer file listings and irreproducible graphs, since these can be easily obtained from the ENDF files with the use of standard editing or plotting programs. In a few instances, sections of the formal document were reproduced. Materials for which no summary documentation has been received to date, are represented by the (File 1) comments contained in the data file only.

The loose leaf-independent section format was selected for ease of updating when more documentation and/or evaluations become available. It is hoped that in the future a more standardized documentation will make the updating simplified.

The publication is presented in sections, each section describing one (or more) ENDF evaluations. These sections are identified and ordered by element number (Z) and atomic weight (A). Sections describing more than one ENDF material are identified by the Z-A numbers of the lowest material described. The section number corresponding to a particular data set should be determined using the table of contents.

(e.g., ^{6}Li(MAT=1115) is described in Section 3-6, whereas ^{133}Cs(MAT=1141) is described in Section 47-107, which also includes ^{107}Ag and ^{109}Ag.)

The ENDF/B-III Library contains 230 materials. (A material may consist of an isotope, element, molecule, or standard mixture of elements.) Ten of these materials contain thermal scattering law data only. Eighty-seven materials consist of photon interaction cross sections for elements. The summary documentations presented in this volume describe the principal part of the library consisting of the remaining 133 materials with neutron cross sections specified for all relevant reactions.

The documentation for a number of "lumped" fission product materials is given following the section of the corresponding fissionable material.

For additional information concerning the evaluated files as well as the corresponding experimental data, contact:

National Neutron Cross Section Center
Brookhaven National Laboratory
Upton, New York 11973

LIST OF AUTHORS AND REFERENCES

Z-EL-A	MAT	LABORATORY	REFERENCE	DATE	AUTHORS (NOTES)
1-H-1	1148	LASL	LA-4574 (1971)	OCT70	L.STEWART.ET.AL(STANDARD H-1 N,P)
1-H-2	1120	BNW,BNL	BNW (PRI.COMM.1967)	JUN67	LEONARD,STEWART(MOD.BY BNL)
2-HE	1088	ANL	ANL-7462(OCT.1968)	JUN68	E.M.PENNINGTON (NATURAL ELEMENT)
2-HE-3	1146	LASL	LASL(PRI.COMM.1971)	1968	L.STEWART (STANDARD HE-3 N,P)
3-LI-6	1115	LASL	AWRE O-60/64(IN PART)	AUG71	BATTAT,LABAUVE(STANDARD LI-6 N,A)
3-LI-7	1116	LASL	AWRE O-61/64(IN PART)	MAR71	BATTAT,LABAUVE(MOD. DFN=215A)
4-BE-9	1154	LLL	UCRL-74533 (DEC 72)	DEC71	R.J.HOWERTON, S.T.PERKINS
5-B-10	1155	LASL,ORNL	ORNL-TM-1872(OCT 67)	JAN72	D.IRVING,R.LABAUVE(STANDARD B-10)
5-B-11	1160	GE,BNL	DFN=49A	SEP71	C.COWAN (AWRE DATA MOD 1971)
6-C-12	1165	KAPL	KAPL-3099(JUN 66)	JAN72	C.LUBITZ ET.AL.(STANDARD TOTAL)
7-N-14	1133	LASL	LA-4725 (SEP 72)	JAN71	P.G.YOUNG,D.G.FOSTER,JR
8-O-16	1134	LASL	LA-4780 (AUG 72)	AUG71	P.G.YOUNG,D.G.FOSTER,JR
11-NA-23	1156	WARD,ORNL	WARD-4181-2 (FEB 71	1971	PAIK,PITTERLE(WARD) PEREY(ORNL)
12-MG	1014	ANL	ANL-7387(MAR 68)	SEP66	E.M.PENNINGTON,J.C.GAJNIAK
13-AL-27	1135	LASL	LA-4726 (DEC 72)	APR71	D.G.FOSTER,JR.,P.G.YOUNG
14-SI	1151	BNL,GGA	GA-8628 (MAY 68)	AUG71	M.K.DRAKE (MOD.BY R.KINSEY AUG71)
17-CL	1149	GGA	GA-7829 VOL 4 (67)	FEB67	M.S.ALLEN,M.K.DRAKE
19-K	1150	GGA	GA-7829 VOL 5 (67)	FEB67	M.K.DRAKE
20-CA	1152	ORNL,GGA	GA-7829 VOL 6 (67)	OCT71	F.PEREY(ORNL) M.K.DRAKE(GGA)
22-TI	1144	ANL	TO BE PUBL.	MAR71	A.B.SMITH
23-V	1017	ANL	ANL-7387 (MAR.68)	SEP66	E.M.PENNINGTON,J.C.GAJNIAK
24-CR	1121	WNES,BNL	WCAP-7281(1969)	JUL70	AZZIZ,CORNYN(WNES) DRAKE(BNL)
25-MN-55	1019	BNL	BNL-50060 (JUN.67)	JUN67	STEPHENSON,PRINCE,PEARLSTEIN
26-FE	1180	ORNL	ORNL-4617 (1970)	JAN72	PENNY,KINNEY,ET.AL.(DATA MOD.72)
27-CO-59	1118	BNL	TO BE PUBL.	1971	T.E.STEPHENSON, A.PRINCE
28-NI	1123	WNES,BNL	WCAP-7387 (1969)	JUN71	AZZIZ,CORNYN(WNES) DRAKE(BNL)
29-CU	1087	AI	AI-AEC-12741(DEC.68)	SEP68	J.M.OTTER ET.AL.(+UKNDL EVAL)
29-CU-63	1085	AI	AI-AEC-12741(DEC.68)	SEP68	J.M.OTTER ET.AL.(+UKNDL EVAL)
29-CU-65	1086	AI	AI-AEC-12741(DEC.68)	SEP68	J.M.OTTER ET.AL.(+UKNDL EVAL)
36-KR-83	1201	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
40-ZR-95	1202	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
41-NB-93	1164	GGA	GA-8133+ADD (67)	JAN67	ALLEN,DRAKE,MATHEWS (MOD SEP 71)
41-NB-95	1203	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
42-MO	1111	ANL	ANL-7387 (1968)	OCT66	E.PENNINGTON (MOD. OCT 69)
42-MO-95	1204	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
42-MO-97	1205	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
42-MO-98	1206	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
42-MO-99	1207	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
42-MO-100	1208	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
43-TC-99	1137	B+W	BAW-1367	OCT71	Z.LIVOLSI
44-RU-101	1210	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
44-RU-102	1211	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
44-RU-103	1212	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
44-RU-104	1213	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
44-RU-105	1214	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
44-RU-106	1215	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
45-RH-103	1125	B+W	BAW-1367	OCT71	Z.LIVOLSI
45-RH-105	1217	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
46-PD-105	1218	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
46-PD-106	1219	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
46-PD-107	1220	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
46-PD-109	1221	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
47-AG-107	1138	BNL	TO BE PUBL.	OCT71	M.R.BHAT AND A.PRINCE
47-AG-109	1139	BNL	TO BE PUBL.	OCT71	M.R.BHAT AND A.PRINCE
48-CD-113	1223	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
53-I-131	1224	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
53-I-135	1225	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
54-XE-131	1226	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
54-XE-133	1227	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
54-XE-135	1026	BNW	PRI.COMM.1967	JUN67	B.R.LEONARD,K.B.STEWART
55-CS-133	1141	BNL	TO BE PUBL.	OCT71	M.R.BHAT AND A.PRINCE
55-CS-135	1229	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
55-CS-137	1230	B+W,WADCO	HEDL-TME 71-106(1971)	JUL71	SCHENTER,SCHMITTROTH,LIVOLSI
57-LA-139	1231	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
58-CE-141	1232	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
59-PR-141	1233	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
59-PR-143	1234	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI

LIST OF AUTHORS AND REFERENCES

Z-EL-A	MAT	LABORATORY	REFERENCE	DATE	AUTHORS (NOTES)
60-ND-143	1235	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
60-ND-145	1236	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
60-ND-147	1237	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
61-PM-147	1238	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
61-PM-148G	1239	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI (GROUND STATE)
61-PM-148M	1254	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI (META-STABLE STATE)
61-PM-149	1240	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
61-PM-151	1241	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
62-SM-147	1242	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
62-SM-148	1243	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
62-SM-149	1027	BNW	PRI.COMM.1967	JUN67	B.R.LEONARD.JR. AND K.B.STEWART
62-SM-150	1244	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
62-SM-151	1245	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
62-SM-152	1246	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
62-SM-153	1247	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
63-EU-151	1028	BNW	PRI.COMM.1970	JUN70	B.R.LEONARD.JR. AND K.B.STEWART
63-EU-153	1029	BNW	PRI.COMM.1967	JUN67	B.R.LEONARD.JR. AND K.B.STEWART
63-EU-154	1248	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
63-EU-155	1249	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
63-EU-156	1250	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
63-EU-157	1251	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
64-GD	1030	ANL	ANL-7387 (MAR 68)	OCT66	E.M.PENNINGTON, J.C.GAJNIAK
64-GD-155	1252	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
64-GD-157	1253	B+W	BAW-409 (NOV 71)	JUL71	LIVOLSI
66-DY-164	1031	BNW	PRI.COMM.1967	JUN67	B.R.LEONARD.JR. AND K.B.STEWART
71-LU-175	1032	BNW	PRI.COMM.1967	JUN67	B.R.LEONARD.JR. AND K.B.STEWART
71-LU-176	1033	BNW	PRI.COMM.1967	JUN67	B.R.LEONARD.JR. AND K.B.STEWART
73-TA-181	1126	AI	AI-AEC-12990(1971)	APR71	OTTER,DUNFORD,OTTEWITTE
73-TA-182	1127	AI	AI-AEC-12990(1971)	APR71	OTTER,DUNFORD,OTTEWITTE
74-W-182	1060	GE-NMPO	GEMP-448 (NOV 66)	NOV66	A.PRINCE,W.B.HENDERSON ET.AL.
74-W-183	1061	GE-NMPO	GEMP-448 (NOV 66)	NOV66	A.PRINCE,W.B.HENDERSON ET.AL.
74-W-184	1062	GE-NMPO	GEMP-448 (NOV 66)	NOV66	A.PRINCE,W.B.HENDERSON ET.AL.
74-W-186	1063	GE-NMPO	GEMP-448 (NOV 66)	NOV66	A.PRINCE,W.B.HENDERSON ET.AL.
75-RE-185	1083	GE-NMPO	GEMP-587	JAN68	W.B.HENDERSON, J.W.ZWICK
75-RE-187	1084	GE-NMPO	GEMP-587	JAN68	W.B.HENDERSON, J.W.ZWICK
79-AU-197	1166	BNW,BNL	PRI.COMM 67,72)	JAN72	LEONARD,STEWART(STANDARD N,GAMMA)
82-PB	1136	ORNL	ORNL-4765 (MAR 72)	JUL71	C.Y.FU AND F.PEREY
90-TH-232	1117	B+W	BAW-317 (1970)	NOV66	WITTKOPF,ROY,LIVOLSI (REV.APR70)
91-PA-233	1119	BAPL	PRI.COMM.(1970)	JAN70	P.C.YOUNG,D.R.HARRIS
92-U-233	1110	BAPL	WAPD-TM-691(1969)	MAR71	N.M.STEEN (DATA MOD.MARCH 71)
FISS.PROD.	1042	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.PROD.	1066	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.PROD.	1067	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.FRAG	1255	B+W	TO BE PUBL.	AUG71	Z.LIVOLSI
92-U-234	1043	GGA	GA-8135(1967)	JAN67	M.K.DRAKE,P.NICHOS
92-U-235	1157	AI,BNW,ANC	BNWL-1586,ANCR-1044	AUG71	ALTER,DUNFORD,LEONARD,PITTERLE
FISS.PROD.	1045	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.PROD.	1068	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.PROD.	1069	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.FRAG	1256	B+W	TO BE PUBL.	AUG71	Z.LIVOLSI
92-U-236	1163	SRL	TO BE PUBL.	OCT71	F.J.MC CROSSON
92-U-238	1158	HARD	HARD-4181-1 (AUG 71)	AUG71	T.A.PITTERLE AND C.DURSTON
93-NP-237	1145	BNW	TO BE PUBL.	MAY69	B.R.LEONARD
94-PU-238	1050	AI	NAA-SR-12271(1967)	MAY67	H.ALTER AND C.DUNFORD
94-PU-239	1159	BNL,BNW,ANC	BNL-50388,ANCR-1045	AUG71	PRINCE,LEONARD,SMITH,PITTERLE
FISS.PROD.	1052	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.PROD.	1070	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.PROD.	1071	B+W	BAW-320 (DEC.66)	DEC66	W.A.WITTKOPF(FOR THERM.REACTORS)
FISS.FRAG	1257	B+W	TO BE PUBL.	AUG71	Z.LIVOLSI
94-PU-240	1105	GGA,BNW	PRI.COMM.CSEWG 1969	SEP69	MATHEWS,PITTERLE,LEONARD,PRINCE
94-PU-241	1106	BNL,AI	PRI.COMM.1969	NOV69	E.OTTEWITTE AND A.PRINCE
FISS.FRAG	1258	B+W	TO BE PUBL.	AUG71	Z.LIVOLSI
94-PU-242	1161	AI,ANC	NAA-SR-12271(MAY67)	AUG71	ALTER(AI) MOD.BY YOUNG+GRIMESEY
95-AM-241	1056	ANC	PRI.COMM.(NOV.66)	NOV66	J.R.SMITH AND R.A.GRIMESEY
95-AM-243	1057	ANC	PRI.COMM.(NOV.66)	NOV66	J.R.SMITH AND R.A.GRIMESEY
96-CM-244	1162	AI,ANC	NAA-SR-12271(MAY67)	AUG71	ALTER(AI) MOD.BY BERRETH (ANC)

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EVALUATED NUCLEAR DATA FOR HYDROGEN IN THE ENDF/B-II FORMAT

by

L. Stewart, R. J. LaBauve, and P. G. Young

ABSTRACT

The following nuclear data are given for hydrogen in the energy range from 1.0×10^{-5} eV to 20.0 MeV.

File 1. The general information file includes a brief description of the data to follow.

File 2. Values for nuclear spin and effective scattering radius are given in the resonance file.

File 3. Smooth cross-section data are given for the total cross section, the free-atom elastic scattering cross section, and the radiative capture cross section; data for $\bar{\mu}$, ξ, and γ are also included.

File 4. The angular distributions for elastic scattering are given as probability vs cosine of the scattering angle.

File 7. The free-atom-scattering cross section is the only information provided at thermal.

File 12. Secondary gamma-ray production multiplicities for capture, which are equal to one, are given in this file.

File 14. Gamma-ray angular distributions are provided for the single radiative capture gamma ray.

INTRODUCTION

This evaluation for hydrogen (MAT = 1148) differs from the previous ENDF/B evaluation (MAT = 1001) in that the elastic scattering data were taken from recent work by Hopkins and Breit[1] and the data for radiative capture were taken from recent work by Horsley.[2] Also, gamma-ray production data, not given in the MAT = 1001 evaluation, are included. A complete listing for MAT = 1148 is given in the Appendix.

FILE 1: GENERAL INFORMATION

A brief summary of the data to follow is given in File 1. The atomic mass for hydrogen was taken to be 1.007825 from the May 1969 "Chart of the Nuclides."[3]

FILE 2: RESONANCE INFORMATION

Nuclear spin and effective scattering radius are given in this file. An effective scattering radius of 1.2756×10^{-12} cm is consistent with a potential scattering cross section of 20.449 b, as determined from $4\pi a^2$. Singlet and triplet scattering radii are not included.

FILE 3: SMOOTH CROSS SECTIONS

Total cross sections (MT = 1) were obtained by adding the elastic scattering and radiative capture cross sections at all energies (1.0×10^{-5} eV to 20.0 MeV). The hydrogen total cross sections are shown in Fig. 1.

The elastic scattering cross sections (MT = 2) were taken from an extensive theoretical treatment of fast neutron measurements by Hopkins and Breit.[1] In this work, a consistent set of cross sections and angular distributions were obtained by using a set of phase shifts previously determined at Yale University.[4] Tabular values of the elastic scattering cross section are given in Ref. 1 for only a few energies, the two lowest points being 100 and 200 keV. The phase shift program and the Yale phase shifts were provided by Hopkins[1] so that many intermediate points could be calculated. At 0.1 keV, the lowest energy recommended for running this program, the scattering cross section is 20.4488 b. This value is in excellent agreement with the thermal cross section (20.442 ± 0.023 b) derived by Davis and Barschall[5] from a revised value of the effective range obtained by determining the best values of the neutron energies from many experiments below 5 MeV performed since 1950. Therefore, for this evaluation, the free-atom-scattering cross section is assumed to be constant below 100 eV and equal to the value calculated from the Yale phase shifts at 100 eV, giving a thermal cross section of 20.449 b. At higher energies, these theoretical predictions are in excellent agreement with the recent measurements of Davis[6] giving an average value of 0.84 for the square of the deviation for energies below 20.0 MeV. The elastic cross section for hydrogen from 1.0×10^{-5} eV to 20.0 MeV is shown in Fig. 2.

The cross sections for radiative capture (MT = 102) were taken from the 1966 publication of Horsley,[2] where a value of 332 mb was adopted for the thermal value. Deuteron photodisintegration cross sections were also employed in deriving radiative capture in Horsley's report. Although the Nuclear Data article by Horsley[2] was referenced for MAT = 1001, the values were taken from an early version described in AWRE 0-23/65, and these were later revised for the Nuclear Data article. The latter report (Ref. 2) has been used for this evaluation, as suggested by Horsley. The radiative capture cross section for MAT = 1148 from 1.0×10^{-5} eV to 20.0 MeV is shown in Fig. 3.

The average value of the cosine in the laboratory system ($\bar{\mu}_L$) for elastic scattering (MT = 251) was derived from the secondary angular distributions in File 4 (MT = 4). Values for $\bar{\mu}_L$ from 1.0×10^{-5} eV to 20.0 MeV are shown in Fig. 4.

Values for ξ, the average logarithmic energy change per collision (MT = 252), and for γ, the Goertzel-Greuling constant (MT = 253), are taken equal to 1 over the range 1.0×10^{-5} eV to 20.0 MeV, following the MT = 1001 evaluation.

FILE 4: SECONDARY ANGULAR DISTRIBUTIONS

Angular distributions of secondary neutrons resulting from elastic scattering are tabulated from 1.0×10^{-5} eV to 20.0 MeV. Distributions at 0.1, 5, 10, 20, and 30 MeV are provided by Ref. 1; additional and intermediate data were calculated by using the Hopkins-Breit phase shift program and the Yale phase shifts. As shown in Figs. 5 through 16, the angular distributions above 100 keV are neither isotropic below 10 MeV, nor are they symmetric about 90° at higher energies as assumed in the earlier version (MAT = 1001). At 100 keV, the angular distributions are assumed to be isotropic because the 180/0° ratio is very nearly unity (1.0011). At 500 keV, this ratio approaches 1.005; therefore, the pointwise normalized probabilities as a function of the cosine of the scattering angle are provided at 1.0×10^{-5} eV (isotropic), 100 keV (isotropic), 500 keV, and at 1-MeV intervals from 1 to 20 MeV.

FILE 5: THERMAL DATA

Free-atom cross sections specified from 1.0×10^{-5} eV to 5 eV are included in this file.

FILE 12: PHOTON PRODUCTION CROSS SECTIONS

A multiplicity representation is used to describe the single hydrogen radiative capture gamma ray from 1.0×10^{-5} eV to 20.0 MeV. The multiplicity is referred to MT = 102 in File 3 and is unity at all neutron energies. To adequately represent the gamma-ray energy for MeV-incident neutrons, the neutron energy region from 0.2 to 20 MeV is divided into 16 different energy bands, and the gamma-ray energy is tabulated for each neutron energy band as

$$\bar{E}_\gamma = 2.225 \times 10^6 + \bar{E}_n/2 \qquad \text{(eV)} ,$$

where $\bar{E}_n$ is the neutron energy at the midpoint of the band in eV. The value 2.225×10^6 eV corresponds to the deuteron binding energy; that is, the small energy change due to the nuclear recoil that accompanies gamma emission has been ignored.

FILE 14: GAMMA-RAY ANGULAR DISTRIBUTIONS

The gamma-ray angular distributions are assumed to be isotropic at all neutron energies from 1.0×10^{-5} eV to 20.0 MeV.

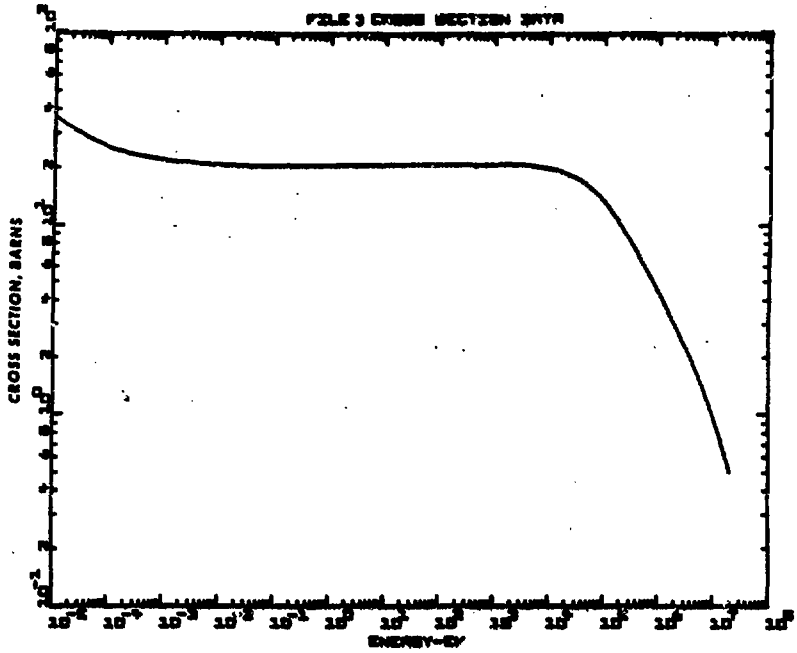

Fig. 1. Total cross section (MT = 1).

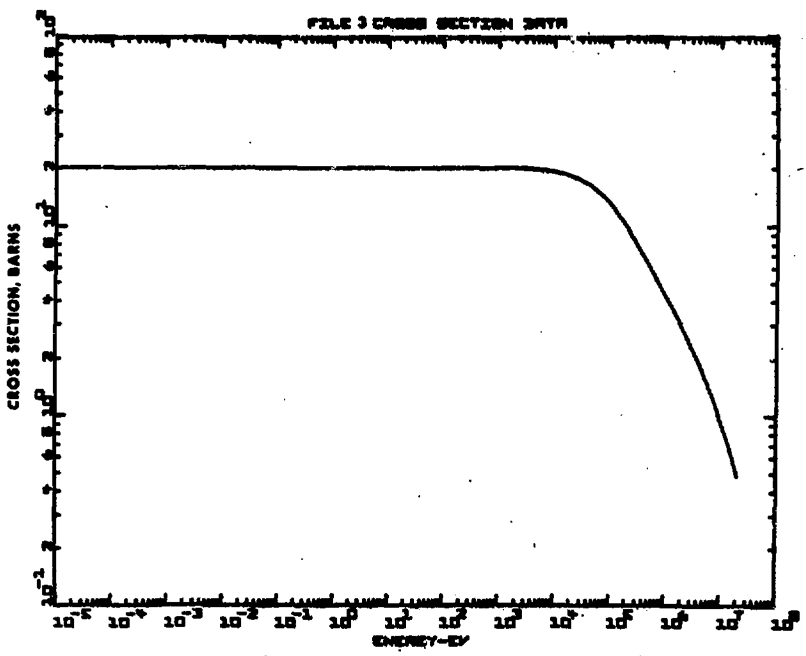

Fig. 2. Elastic scattering cross section (MT = 2).

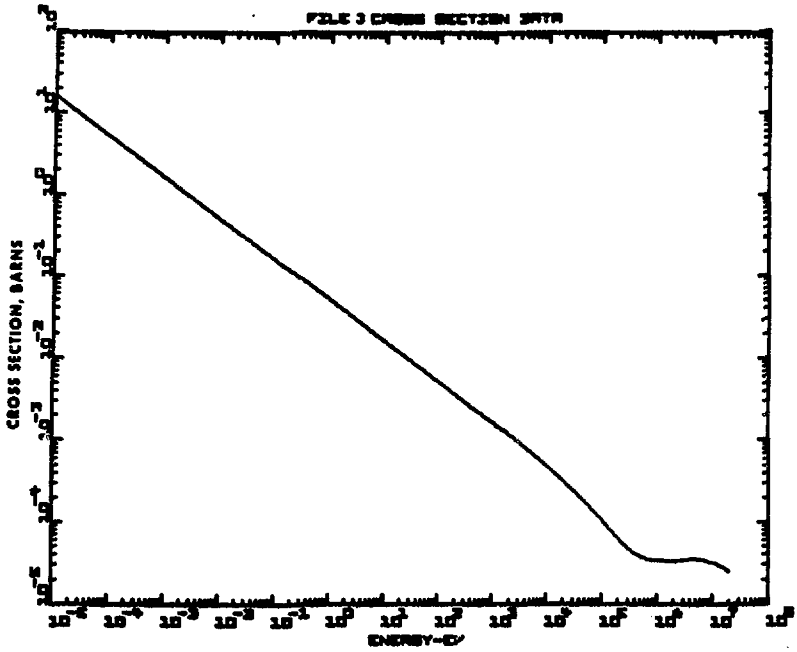

Fig. 3. Radiative capture cross section (MT = 102).

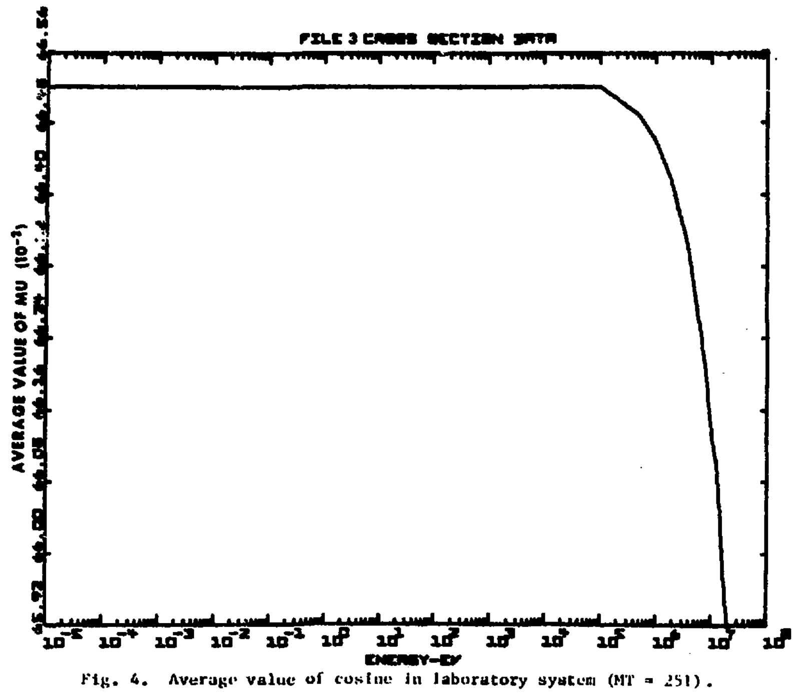

Fig. 4. Average value of cosine in laboratory system (MT = 251).

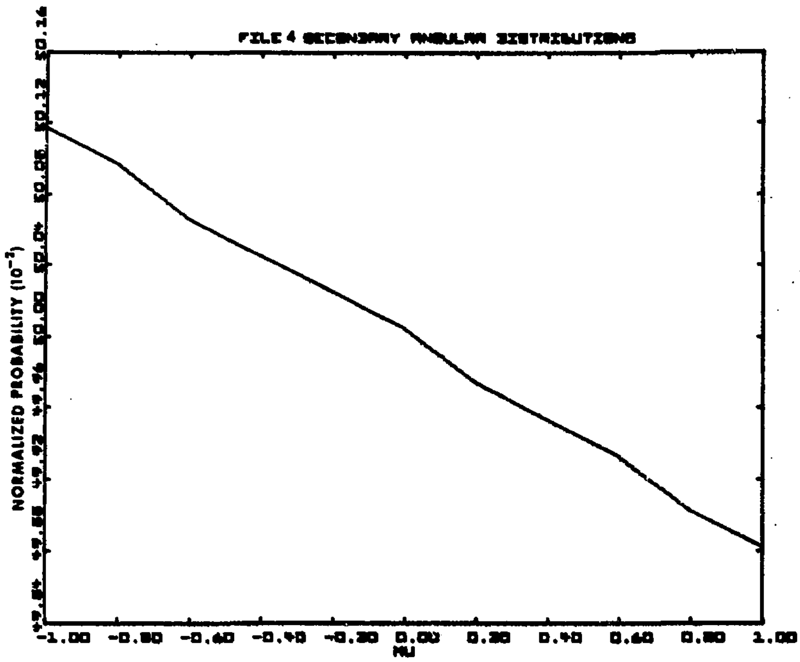

Fig. 5. Angular distribution for 0.5 MeV.

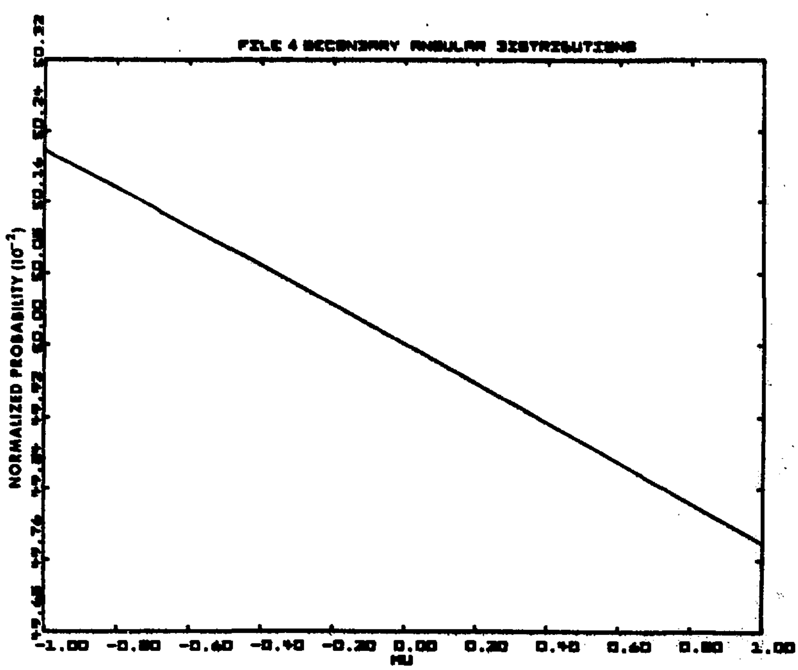

Fig. 6. Angular distribution for 1.0 MeV.

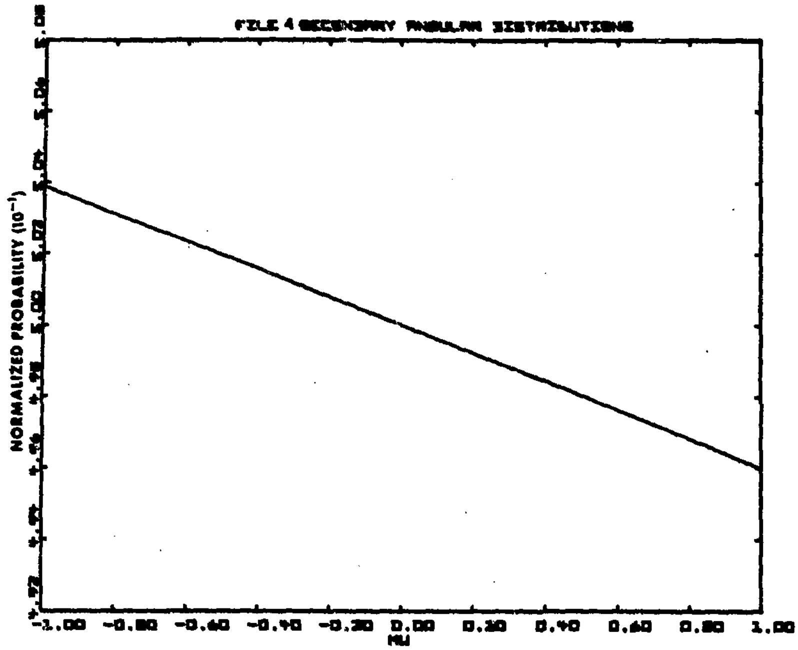

Fig. 7. Angular distribution for 2.0 MeV.

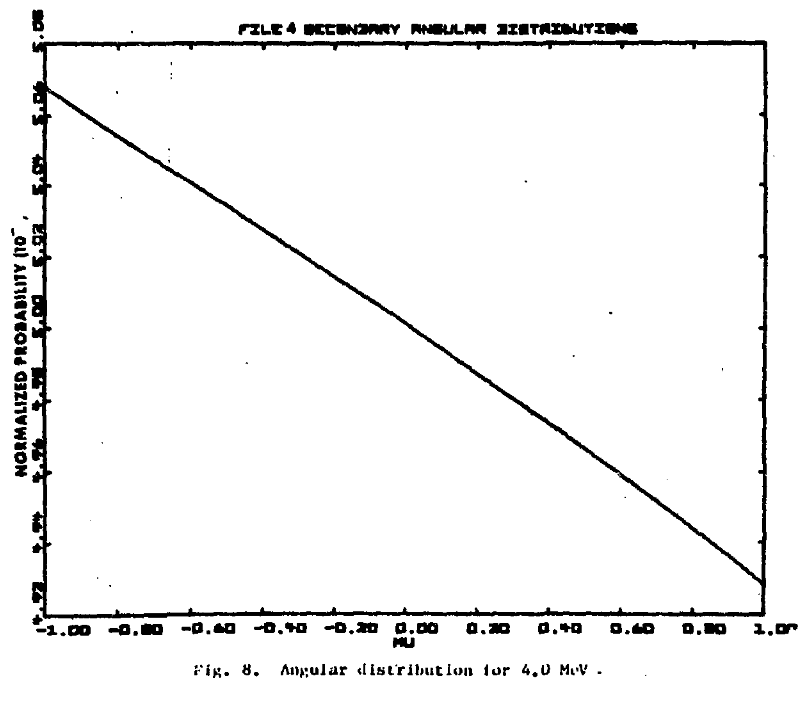

Fig. 8. Angular distribution for 4.0 MeV.

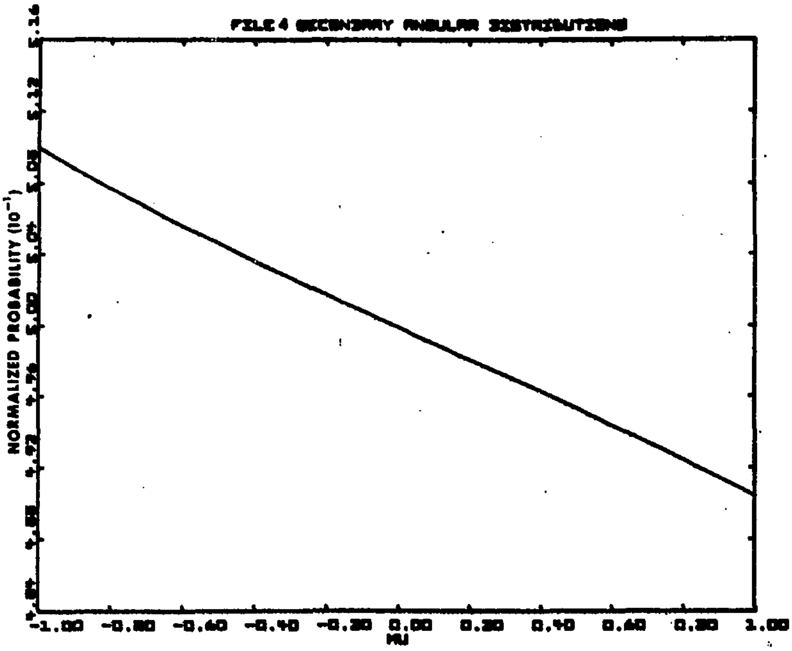

Fig. 9. Angular distribution for 6.0 MeV.

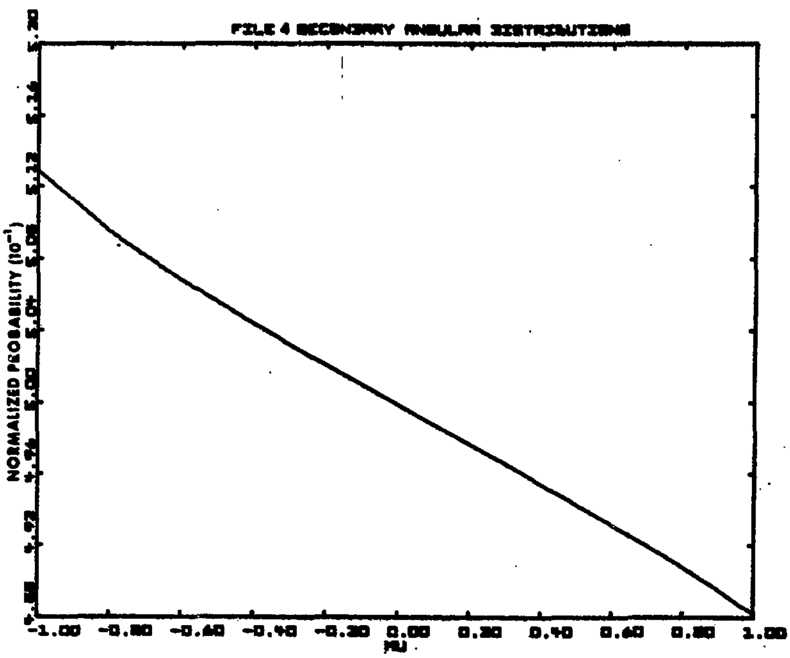

Fig. 10. Angular distribution for 8.0 MeV.

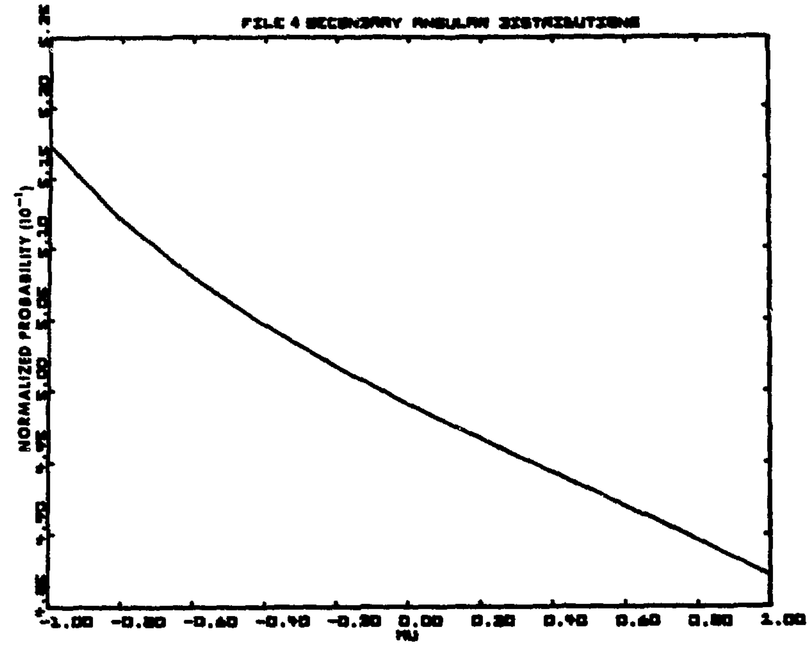

Fig. 11. Angular distribution for 10.0 MeV.

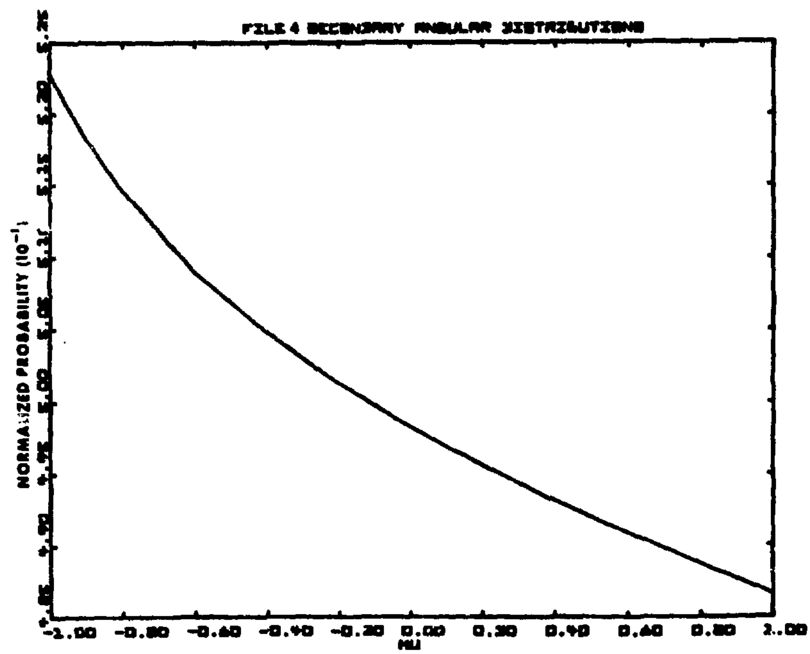

Fig. 12. Angular distribution for 12.0 MeV.

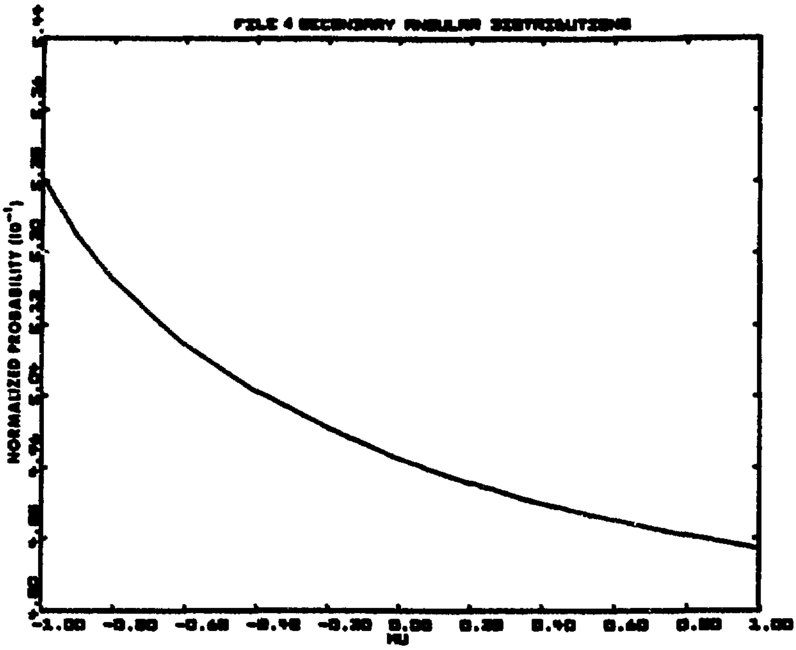

Fig. 13. Angular distribution for 14.0 MeV.

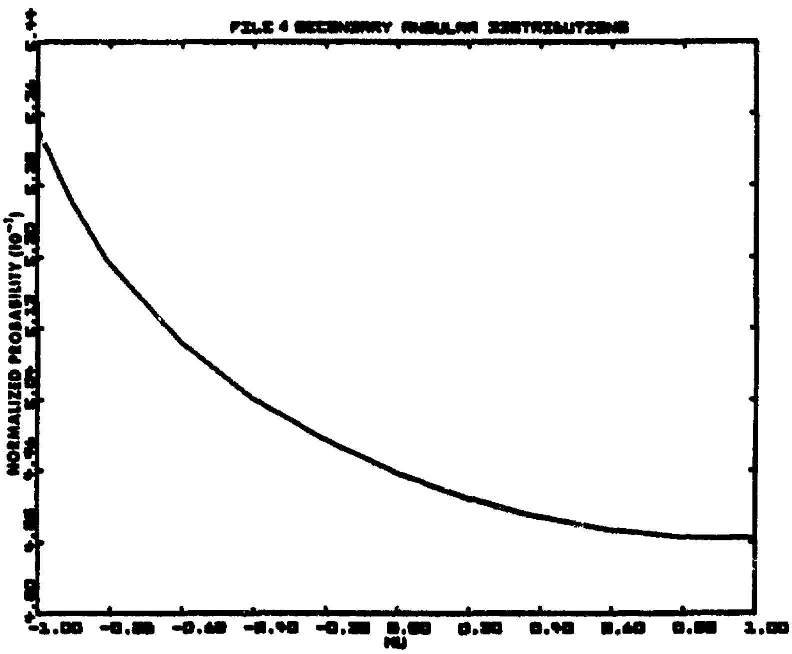

Fig. 14. Angular distribution for 16.0 MeV.

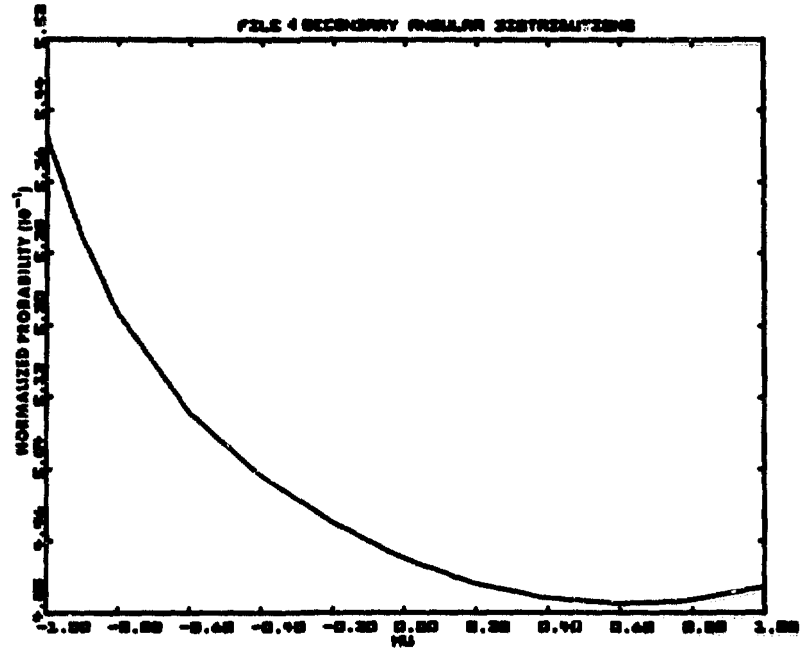

Fig. 15. Angular distribution for 18.0 MeV.

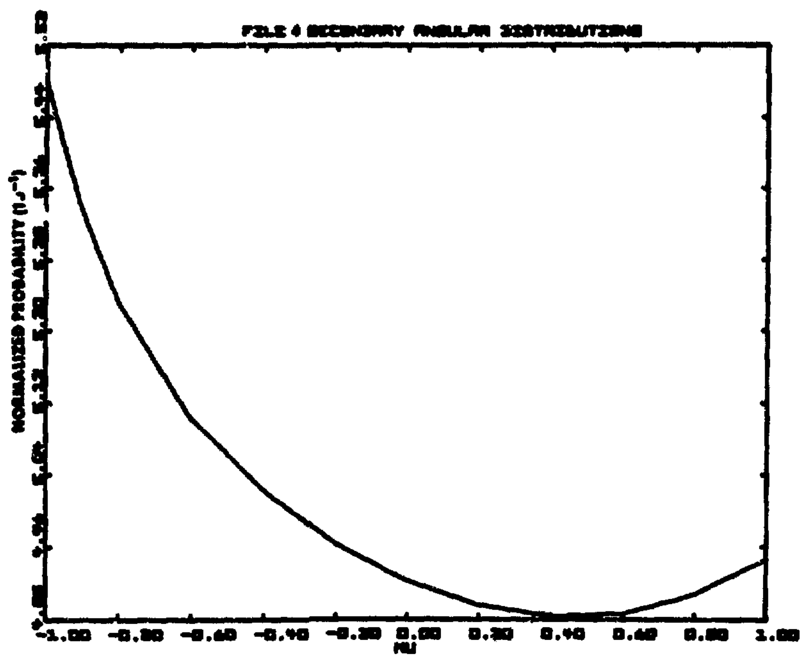

Fig. 16. Angular distribution for 20.0 MeV.

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1-H-2 1120 BNW.BNL BNW (PRI.COMM.1967) JUN67 LEONARD.STEWART(MOD.BY BNL)

DEUTERIUM (HYDROGEN-2)

General Identification

MAT = 1003
ZA = 1002.0
AWR = 1.997

[Everling][1]

$$\frac{Md}{Mn} = \frac{2.0141102.19}{1.008665} = 1.997$$

Evaluations Considered

UNC-5038	Ref 2
GA-2156	Ref 3
TID-21629	Ref 4
LASL Library (June 1966)	Ref 5
BNL-325, 2nd Ed (1964)	Ref 6

Radioactive Decay

Tritium: λ = 1.79E-09 [Nuclear Data][7]

Cross Sections

Total (MT=1)

There are new total cross-section data of Foster and Glasgow[8] in the energy region of 2.5- to 15-MeV. The validity of these data is fairly well substantiated: 1) The method of substitution using a CD_2 sample and carbon blank was identical to that used by the same experimenters for hydrogen which led to excellent agreement with previous measurements, and 2) the CD_2 sample used was the same sample used in the measurements at LRL-Livermore.[9] These new measurements have necessitated a reevaluation of the total cross section, particularly for energies $\leq\sim 8$ MeV. Consideration has been given to all known data as of July 1, 1966.[10] The data were fitted to simple functions to assure a smooth behavior of the cross section. In view of some obvious systematic discrepancies, a least-squares fitting procedure was judged to be of little value. A good fit to the data was obtained with the expression:

$$\sigma_T(E) = \frac{3.952}{1 + .2826E} - .77 \exp[-1.316E] \text{ barns} \qquad [1]$$

where E is in MeV.

This fit to high-energy cross sections (E $\geq$ 100 keV) extrapolates to the zero energy value of 3.182 barns. Although this value is significantly lower than others previously proposed [e.g., BNL-325 (6) gives 3.38 ± .05 barn] it is difficult to conceive of a smooth extrapolation of the high energy data which would give a significantly higher value. Other reviewers [Stewart and Horsley][11] have also arrived at a value of about 3.20 barns.

There are some serious discrepancies with this proposed value. The coherent scattering cross section of deuterium has been established to be 5.76 ± 0.14 barns (12) which gives a free atom value of 2.56 ± 0.6 barns. Thus the incoherent bound atom cross section should be

$$\frac{3.18 - 2.56}{\left[\frac{MD/Mn}{(MD/Mn) + 1}\right]^2} = 1.40 \pm .06 \text{ barns.}$$

However, the only precise measurement (13) which does not depend on the value of σ_T (free atom) gives 2.25 ± .04 b. This discrepancy does not seem reconcilable with presently available data. The value of 3.18 b for the deuterium free atom cross section is consistent with the measured cross section of D_2O in the energy region of about 1 keV.

The total cross section given in ENDF/B is tabulated as 26 point values calculated from Equation (1) over the energy range of 10^{-4} eV to 20 MeV.

n,2n (MT=16)

The only data available for consideration were those of Catron, et al.[14] These data appeared to be nearly linear in σ vs ℓnE and were fitted to the expression:

$$\sigma = 323\ \ell nE - 189.6 \text{ mb} \qquad [2]$$

for energies above threshold. The n,2n cross section is given as 18 point values calculated from Eq. (2) with σ-ℓnE interpolation after the first two values.

Elastic (MT=2)

The elastic cross section is derived from the total - n,2n discussed previously. The entries in ENDF/B are 26 point values from 10^{-4} eV to 20 MeV with ℓn-ℓn interpolation above 10^3 eV.

Capture (MT=102)

BNL-325 (1964)[6] lists four measurements which are badly discrepant. However, the value of 0.37 mb reported by Sargent, et al[15] has been revised to 0.53 mb according to a private communication[16] and a new measurement from Chalk River reports a preliminary value of 0.506 ± .005 mb.[17] Thus the values to be considered are:

0.60 ± .05 mb	(18)
0.57 ± .01	(19)
0.53 ± .12	(16)
0.506 ± .005	(17)
0.362 ± .026	(20)

In view of these results the values given in ENDF/B were normalized to 0.51 mb.

The capture cross section above 0.25 MeV has been calculated from detailed balance from the cross section for photodisintegration of the Triton.[21] The results of these calculations agree well with the measurements of Bösch, et al[22] over the energy range of .8 to 4 MeV. Although the calculations are preliminary they have been used to generate the ENDF/B values. The values are listed in ENDF/B as 33 point values from 10^{-4} eV to 20 MeV with ℓn-ℓn interpolation.

Angular Distributions

There are a number of tables of Legendre coefficients derived from experimental angular distributions. The values derived in UNC-5038[2] appeared to consider all of the pertinent data. UNC-5038 lists six Legendre coefficients at closely-spaced energy intervals from 0 to 18 MeV. For the ENDF/B file, coefficients are listed at 35 energy values which were judged to give a sufficiently fine mesh to accurately reproduce the distributions.

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2-HE 1088 ANL ANL-7462(OCT.1968) JUN68 E.M.PENNINGTON (NATURAL ELEMENT)

NATURAL HELIUM

by

E. M. Pennington
Argonne National Laboratory
July 1968

General Identification

MAT=1088

ZA =2000.0

AWR=3.96822

Abundances:	He-3	0.0000013
	He-4	0.9999987

Data Included

Because of the low abundance of He-3, only its (n,p) cross section, which is very large at low energies, need be considered. Elastic scattering is the only possible reaction for neutrons incident on He-4 at energies below 15 MeV. Thus the elastic scattering cross section and values of $\bar{\mu}_L$, ξ, and γ are given in File 3, and elastic scattering Legendre coefficients are given in File 4. Parameters for a free gas thermal scattering law are in File 7.

Data Sources

The elastic scattering cross section and the Legendre expansion coefficients were calculated from s-, p-, and d-wave phase shifts using a Fortran program written for the purpose. The phase shifts were read from smooth curves based on Table I of Ref. 1. At energies below the

300 keV lower limit of Table I, each of the two p-wave phase shifts was obtained by assuming a functional form based on the low energy limit for a single p-wave resonance, with parameters determined from fitting the low energy phase shifts of Table I. The s-wave phase shift below 300 keV was calculated using hard sphere scattering and a nuclear radius, a = 2.4 Fermi. This yields the thermal scattering cross section = $4\pi a^2$ = 0.7238 barns in agreement with the experimental value of 0.73±0.05 barns (Ref. 2). The low energy s-wave phase shifts of Table I are consistent with a nuclear radius of about 2.48 Fermi and so would yield a somewhat high thermal cross section.

Values of $\bar{\mu}_L$, ξ, and γ were calculated from the Legendre coefficients using a Fortran program, MUXIGA. This program uses the equations of Ref. 3-5.

An elastic scattering transformation matrix from the center-of-mass system to the laboratory system was computed using CHAD (Ref. 6).

The (n,p) cross section for He-3 is that recommended in the evaluation of He-3 by J. Als-Nielsen given in Ref. 7. Extension from 10 to 15 MeV was made using linear extrapolation on a log σ - log E scale.

The total cross section is the sum of the elastic scattering and (n,p) cross sections.

Comments

The phase shifts of Ref. 1 are optical model phase shifts chosen to fit both angular distribution and polarization data at many energies. The total scattering cross section is also fit within the scatter of the experimental points. Another recent set of phase shifts (Ref. 8) is not very different from those used here and could also have been used in the present work. There should be no serious errors in the He-4 data calculated from the phase shifts.

As discussed in Ref. 7, the He-3 (n,p) cross section is rather well known. Probably more error is introduced into the (n,p) cross section for natural helium by the uncertainty in the He-3 isotropic abundance than by the uncertainty in the He-3 (n,p) cross section itself.

Previous evaluations of helium for reactor calculations include those of J. J. Schmidt (Ref. 9) and B. R. S. Buckingham et al. (Ref. 10). Schmidt's evaluation includes the (n,p) cross section for He-3 and σ_S, $\overline{\mu}_L$, and a set of phase shifts for He-4. Buckingham et al. give separate evaluations for He-3 and He-4. For He-3, elastic (n,p), (n,d), and (n,2n) cross sections are given, as well as elastic angular distributions. The He-4 evaluation gives σ_S and angular distributions.

The present evaluation will be described in detail in Ref. 11.

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2-HE-3 1146 LASL LASL(PRI.COMM.1971) 1968 L.STEWART (STANDARD HE-3 N,P)

SUMMARY DOCUMENTATION FOR He-3*

L. Stewart and R. J. LaBauve

Los Alamos Scientific Laboratory

ABSTRACT

The following nuclear data are given for ^{3}He in the energy range from 1.0 x 10^{-5} eV to 20 MeV:

File 1. The general description of the data which follow

File 2. Values of the nuclear spin and effective scattering radius

File 3. Smooth point-wise data for the total, the free-atom elastic, (n,p), (n,d), and the radiative capture cross sections; data for $\bar{\mu}$, ξ, and γ are also included

File 4. The angular distributions for elastic scattering as probability vs cosine of the scattering angle in the center-of-mass system

File 7: The free-atom-scattering cross section at thermal

I. INTRODUCTION

These data were translated from an unpublished evaluation completed by L. Stewart in 1968. In 1971, the Standards Subcommittee of CSEWG reviewed the file and concluded that the (n,p) cross section was still adequately represented to be recommended as a standard cross section.

II. TOTAL CROSS SECTION

The total cross section was obtained by summing the partials up to 100 keV. From 100 keV to 20 MeV, the LASL measurements[1] were used exclusively in this evaluation.

III. ELASTIC SCATTERING

Available measurements of Seagrave, Cranberg, and Simmons[2], of Sayres, Jones, and Wu[3], and of Antolković et al.[4] were used. Also the p + T scattering was used to fill the gaps in energy where no n + ^{3}He elastic scattering measurements exist. The p + T experiments employed were those of Brolley et al.[5], Rosen and Leland[6], and of Vanetsian and Fedchenko[7]. Wick's Limit was employed at all energies to insure the nonviolation of unitarity. The angular distributions are given as probabilities versus cosine of the center-of-mass scattering angle.

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* Work done under the auspices of the United States Atomic Energy Commission

IV. RADIATIVE CAPTURE

Gallmann, Kane, and Pixley[8] have placed upper limits on the thermal capture cross section of 100 μb and 10 μb for gamma and pair emission, respectively. Since these are upper limits and absolute measurements do not exist, no estimate is made here for radiative capture. The gamma-ray production cross sections are also assumed to be negligible and are therefore ignored.

V. (n,p) CROSS SECTION

The (n,p) cross section below 10 eV was derived solely from the measurements of Als-Nielsen and Dietrich[9] giving 5327^{+10}_{-9} b at thermal. A 1/v extrapolation was assumed to 1.7 keV, where the slope was changed to merge with the slope of the curve given by the data of Gibbons and Macklin[10,11]. Many experiments[3,12-17] have been performed at higher energies although, all too often, the cross sections were not obtained on an absolute basis. The most extensive absolute measurements were those of Perry et al.[13] which have been heavily weighted in this evaluation.

VI. (n,d) CROSS SECTION

Only the Columbia data[3] near 7.5 MeV were available on this reaction. Bradbury and Stewart[18], however, employed detailed balance and the LASL measurements on the inverse reaction, that is, the $D(d,n)^3He$ reaction, to predict the energy dependent cross section to 15 MeV. Above 15 MeV, these data were extrapolated.

VII. THREE- AND FOUR-BODY BREAKUP

The $^3He(n,np)D$ and $^3He(n,2n2p)$ reactions have Q values of -5.494 and -7.718 MeV, respectively. Only a few measurements exist on these reactions, and these are usually limited to a search for final-state phenomena. The spectrum is usually observed at one angle very close to zero degrees. Observation of the proton spectrum at 14.4 MeV reveals no clear indication of n-d, two-nucleon, or three-nucleon final-state interaction. A strong n-p final state is evident from measurements of the deuteron spectrum at $\theta_d = 5^o$. An upper limit of 12 mb has also been set on the $^3He(n,2n2p)$ reaction. In the absence of measurements of the absolute cross sections, these break-up cross sections have been assumed small and are therefore ignored in the present evaluation.

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3-LI-6 1115 LASL AWRE 0-60/64(IN PART) AUG71 BATTAT.LABAUVE(STANDARD LI-6 N.A)

SUMMARY OF ^{6}Li DATA FOR ENDF/B-III*

by

M. E. Battat and R. J. LaBauve

Los Alamos Scientific Laboratory

INTRODUCTION

The data, in the energy range of 10^{-5} eV to 20 MeV, for ^{6}Li (MAT 1115) were submitted to the NNCSC in September 1971 for inclusion in ENDF/B-III. These data represent an extensive revision of the earlier file (MAT 1005) which was, for the most part, based on a UKAEA evaluation.[1] A major change was made in that below about 1.7 MeV the cross sections for MAT1115 reflect very strongly the detailed review of the available data by Uttley, Sowerby, Patrick and Rae.[2] In choosing the latter data, consideration was also given to the recommendation of the CSEWG Normalization and Standards Subcommittee that Uttley's (n,α) data be used in the latter energy range.[3] The data above 1.7 MeV for MAT 1115 will be discussed in later sections of this document. For this first pass reevaluation, the (n,γ) cross sections from the earlier UK evaluation were retained. Following Uttley et al., the data will be considered in the following energy intervals: (1) thermal, (2) thermal to 10 keV, (3) 10 to 500 keV, and (4) 500 keV to 1.7 MeV. Above 1.7 MeV, the data will be considered by reaction type.

THERMAL ENERGIES

The cross sections given in the file at 0.0253 eV are as follows:

Total	=	941.015 b
Elastic	=	0.72
(n,α)	=	940.25
(n,γ)	=	0.045

It is estimated that the (n,α) cross section is known to ± 0.5%. The choice of Uttley et al. for the (n,γ) cross section is 30 ± 8 mb.

THERMAL ENERGIES TO 10 keV

The (n,α) cross sections up to 100 eV were calculated from the formula

$$\sigma(n,\alpha) = (149.56/\sqrt{E}) - 0.024 \text{ b.}$$

Above 100 eV, the p-wave absorption contribution from the 247-keV resonance becomes increasingly important, and at 10 keV the negative s-wave absorption (-0.024b) is largely cancelled. Uttley et al. assign an uncertainty of ± 1% to the (n,α) cross section from thermal to 10 keV. Over this energy range, the data given in the file deviate from a strict 1/v dependence ($149.56/\sqrt{E}$) by a maximum of -0.4%.

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* Work done under the auspices of the United States Atomic Energy Commission

The elastic cross section is held constant at 0.72 b up to 2 keV with a monotonic increase thereafter to 0.7221 b at 10 keV. The elastic angular distribution up to 10 keV is specified as isotropic in the CM system.

10 to 500 keV

The uncertainties estimated for the (n,α) cross section are:

± 2% at 100 keV, ± 5% from 100 to 300 keV, and
± 10 % at 500 keV.

As can be seen from Fig. 2 of Ref. 2, there is great disagreement among the (n,α) measurements in this energy range. The (n,α) curve used in this evaluation is the one recommended by Uttley et al. based on their careful review of the experimental data. In arriving at the recommended curve, the latter authors have considered the following points:

1. Errors in the energy scales of the measurements.
2. The inadequacy of those experiments in which the cross sections were measured relative to the ^{235}U fission cross section.
3. The inadequacy of those measurements in which the neutron flux was measured relative to a long counter.
4. The inconsistency of measurements made using thick lithium detectors with total and scattering cross section measurements.

Uttley et al. do, however, state that much experimental work[2] remains to be done to confirm their recommendations.

In general, the total cross sections are those reported by Uttley and Diment.[4] The scattering cross sections below and above 100 keV reflect the data of Asami and Moxon[5] and Lane, Langsdorf, Monahan, and Elwyn[6], respectively. For the elastic angular distributions, Legendre coefficients (from which the normalized probability distributions are reconstructed) were inferred by fitting the data of Lane et al.[6]

500 keV to 1.7 MeV

The (n,α) data in this energy range were obtained by subtracting the scattering cross section from the total cross section. The total cross section values were essentially those reported by Diment and Uttley.[4] For the scattering cross sections the measurements of Lane et al.[6] and Knitter and Coppola[7] were considered. The (n,α) cross section uncertainties are estimated to be:

± 10% at 500 keV, increasing to ± 15% between 700 and 1000 keV, and decreasing to ± 10% by 1.7 MeV.

TOTAL CROSS SECTION

From 2 to 15 MeV, the primary reference for the data in the file is the work of Foster and Glasgow.[8] The extrapolation to 20 MeV was based on the measurements of Peterson, Bratenahl, and Stoering.[9]

ELASTIC CROSS SECTION

Data given between 4 and 10 MeV are heavily weighted towards the Hopkins, Drake and Condé evaluation.[10] A value of 0.88 b at 14 MeV was used and data smoothly extrapolated to 20 MeV.

Legendre coefficients for the angular distributions up to 2.5 MeV were determined from the data of Lane et al.[6] Between 4.83 and 7.5 MeV coefficients were inferred from Hopkins et al. data.[10] Based on 14-MeV elastic scattering data given in BNL-400, optical model calculations (ABACUS code) were performed to infer Legendre coefficients between 10 and 20 MeV. Data for Mt 251 ($\bar{\mu}_L$), 252 (ξ), and 253 (γ) were caluclated using the elastic angular distributions given in File 4.

THE (n,2n)αp CROSS SECTION

The cross sections and angular distributions for this reaction (MT = 24) are the same as in Ref. 1 up to 15 MeV with a smooth extrapolation to 20 MeV. The secondary energy distributions given in Ref. 1 have been approximated by ENDF/B Law 9 with $\theta = 0.21\sqrt{E}$ (MeV).

THE (n,n')γ and (n,n')αd CROSS SECTIONS

The (n,n')γ cross sections tabulated under MT = 52 are those measured by Presser, Bass, and Krüger[11] up to 7 MeV, with a constant 5 mb assumed thereafter. Isotropy in the CM system is specified for the angular distribution.

The (n,n')αd data given under MT = 91 are the same as in Ref. 1 up to 3 MeV, with the data of Hopkins et al.[10] taken into account between 4 and 10 MeV. The value of 433 mb assigned at 14 MeV is higher than the 403 mb given in Ref. 1, which is higher than the nominal 330 mb reported experimentally. A more detailed evaluation of the 14-MeV cross sections will be required to resolve the latter discrepancy. The extrapolation to 20 MeV of the (n,n')αd cross section was obtained by subtracting the sum of all other partials from the total cross section. For the angular distributions, the tabulated values of Ref. 1, extrapolated to 20 MeV, were used. The secondary energy distributions of Ref. 1 were approximated using ENDF/B Law 9 with θ values obtained by linear interpolation between the following points:

$E = 1.718$ MeV, $\theta = 0.05$ MeV
$E = 4.1$, $\theta = 0.75$
$E = 20.0$, $\theta = 8.40$

THE (n,p) AND (n,α) CROSS SECTIONS

The (n,p) cross sections up to 7 MeV reflect the data of Presser et al.[11] Above 7 MeV the data of Ref. 1 were used and extrapolated to 20 MeV. For the (n,α) cross sections the data between 2 and 15 MeV are those of Ref. 1. Extrapolation to 20 MeV was based on the measurements of Kern and Kreger[12] between 15 and 18 MeV.

ACKNOWLEDGMENTS

We are indebted to Leona Stewart for providing us with the data below 2 MeV and plots of the angular distributions of Lane et al., and to P. G. Young for performing the optical model calculations.

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SUMMARY OF ^{7}Li DATA FOR ENDF/B-III*

by

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The data for ^{7}Li presently in ENDF/B-III was submitted to the NNCSC in early 1971. Although a new MAT number has been assigned to this isotope, the data are essentially the same as for MAT 1006 submitted earlier. Changes to the latter data were mainly to take account of ENDF/B format changes.

Unless otherwise noted, the ^{7}Li data - Data File Number (DFN) 215, Mark Label A - in the UKAEA nuclear data library are given in this file. Energy range is 10^{-5} eV to 15 MeV. Basic reference for this nuclide is AWRE Report 0-61/64 (July 1964), which gives data for DFN-176. As per AWRE Report 0-55/65 (April 1965), DFN-215 has same data as DFN-176 but with slightly lower elastic cross sections between 0.01 and 0.2 MeV. The data to 10^{-4} eV were added at AEE, Winfrith, in January 1967 and nuclide identified as 215A (see AEEW-M 802, February 1968).

In the summary which follows, MF and MT refer to file and reaction type numbers, respectively.

MF = 1: General Information and Comment Cards.

This file contains essentially the same information as given in this summary documentation.

MF = 2: Scattering radius only.

MF = 3: Smooth Cross Sections.

MT = 1 Total

MT = 2 Elastic

MT = 4 Total inelastic = $(n,n')\gamma$ + $(n,n')\alpha t$

MT = 16 (n,2n)

MT = 24 $(n,2n)\alpha d$

MT = 51 $(n,n')\gamma$

MT = 91 $(n,n')\alpha t$

MT = 102 (n,γ)

MT = 104 (n,d)

*Work done under the auspices of the United States Atomic Energy Commission

MT = 251 $\bar{\mu}_{lab}$: average cosine of the scattering angle in the laboratory system for elastic scattering. Data from H. Alter of Atomics International (private communication).

MT = 252 ξ : average logarithmic energy decrement. Data from H. Alter.

MT = 253 γ : Goertzel-Greuling coefficient. Data from H. Alter

MF = 4: Secondary Angular Distributions. MT numbers as defined in MF = 3 above.

MT = 2 Legendre coefficients in center-of-mass system. Transformation matrix for conversion to Laboratory system is given. Data from H. Alter of Atomics International (private communications).

MT = 16 Tabular form. Laboratory system. Neutron energy range = 8.3 to 15 MeV.

MT = 24 Tabular form. Laboratory system. Neutron energy range=10 to 15 MeV.

MT = 51 Tabular form. Center-of-mass system. Neutron energy range=0.55 to 15 MeV.

MT = 91 Tabular form. Laboratory system. Neutron energy range=2.821 to 15 MeV.

MF = 5: Secondary Energy Distributions. MT numbers as defined in MF = 3 above.

MT = 16 (n,2n). Energy range is 8.3 to 15 MeV. Distribution approximated by ENDF/B Law 9 with

$$\theta = 0.21\sqrt{E} \text{ MeV}$$

This corresponds to an average θ of 0.7 MeV in the 8.3 to 15 MeV energy interval.

MT = 24 (n,2n)αd. Energy range is 10 to 15 MeV. Distribution approximated by ENDF/B Law 9, with

$$\theta = 0.1133\sqrt{E} \text{ MeV.}$$

This corresponds to an average θ of 0.4 MeV in the 10 to 15 MeV energy interval.

MT = 91 (n,n')αt. Distributions approximated using ENDF/B Law 9. Theta values obtained by linear interpolation between the following points:

E = 2.821 MeV, θ = 0.10 MeV

E = 5.8 MeV, θ = 0.70 MeV

E = 8.0 MeV, θ = 2.80 MeV

E = 15.0 MeV, θ = 5.35 MeV

4-BE-9 1154 LLL LLL.(PRI.COMM.1971) DEC71 R.J.HOWERTON. S.T.PERKINS

EVALUATED NEUTRON INTERACTION AND GAMMA-RAY PRODUCTION CROSS SECTIONS OF BE^9 FOR ENDF/B-III

R. J. Howerton and S. T. Perkins

Abstract

The methods used to produce evaluated neutron interaction and photon production cross sections for Version III of ENDF/B are discussed.

I. GENERAL COMMENTS

The neutron energy range covered extends from 0.0001 eV to 20 MeV. In addition to elastic scattering which is everywhere energetically possible, the following reactions have thresholds[1] at energies less than 20 MeV:

Reaction	Threshold (MeV)
n,2n	1.85
n,p	14.26
n,np	18.76
n,d	16.29
n,nd	18.55
n,t	11.60
n,nt	19.65
n,α	0.67
n,nα	2.74
n,γ	exoergic

*This work was performed under the auspices of the U. S. Atomic Energy Commission.

For the (n,np), (n,nd), and (n,nt) reactions, there are no measurements and since the thresholds are sufficiently high, these cross sections are considered negligible. The (n,nα) reaction is a decay mode for the (n,2n) reaction since He^5 is unstable, decaying to a neutron and an alpha particle with a half-life of about $2x10^{-21}$ seconds. The inelastic scattering reaction is also a decay mode for the (n,2n) reaction since the Be^{9*} recoil nucleus always decays to a neutron and two alpha particles. The way in which the cross sections are selected for elastic scattering, (n,2n), (n,p), (n,d), (n,t), (n,α), (n,γ), and (n,Xγ) reactions is discussed below.

II. ELASTIC SCATTERING

A. Cross Section

The free atom cross section is used for all energies below the usual upper limit of the molecular binding energy (about 10 eV). This is effectively only the nuclear part of the cross section of a stationary target at zero degrees Kelvin. It is strongly emphasized that the numbers are meaningless in the absence of a proper thermal treatment by either the processing code or the neutronics code which uses these numbers.

The scattering cross section was taken equal to 6 barns from 0.0001 eV to 0.01 MeV. From this energy to the (n,α) threshold of 0.67 MeV, the scattering cross section is equal to the total cross section because the (n,γ) cross section is essentially negligible. The selected total cross section was based on data of Refs. 2 through 6.

Above the (n,α) threshold, the scattering cross section was taken as the difference between the total and the nonelastic, with the nonelastic being equal to the sum of its parts. From .67 to 2 MeV, the evaluated total cross section was based on Refs. 2 through 9. Above this energy, we relied on the results of Ref. 10 over the 2.7 MeV resonance, and Ref. 11 up to 15 MeV. The extension to 20 MeV was based on data from Refs. 12 through 14. The uncertainty in the cross section is about ±3% below the (n,α) threshold, varying up to ±10% at 14 MeV and ± 20% of 20 MeV.

B. Angular Distributions, Normalized Probabilities

For energies less than 7 MeV, experimental differential scattering data are presented in Refs. 15 through 25. These data were used to determine the normalized probabilities. Below the (n,2n) threshold, total scattering data are made up of only elastic scattering since there is no inelastic scattering. The change in shape of the angular distribution going through the scattering resonances was taken into account. At 14 MeV, the probabilities were based on the results of Refs. 26 through 28. A smooth extrapolation was made to 20 MeV. The results are consistent with Wick's limit at all incident energies. The angular distributions are probably accurate to ±10% for energies less than or equal to 14 MeV. For energies from about 15 to 20 MeV the uncertainty increases with increasing energy and is estimated to be about 30% at 20 MeV.

III. (n,2n) REACTION

A. Cross Section

The (n,2n) cross section is based on the (n,2n) cross sections, and nonelastic minus absorption cross sections referenced in Perkins' work,[29] as well as the new (n,2n) data up to 6.4 MeV given in Ref. 30. The nonelastic results of Ref. 31 appear too large and were not used. The 20 MeV point was based on interpolating nonelastic cross sections between the 14 MeV value and the value at 25.5 MeV quoted in Ref. 32. Below 6.4 MeV, the cross section is probably accurate to $\pm$10%. At 14 MeV, however, it is much worse, the uncertainty being in the range of $\pm$20%, and at 20 MeV about 40%.

B. Energy Distributions, Normalized Probabilities

The ℓ=0 Legendre moment of the transference function has been taken from the work of Perkins.[29,33] Briefly, this treated the (n,2n) reaction as a series of time-sequential decays, $Be^9(n,n_1)Be^{9*}(n_2)Be^{8*}$. Levels excited were at 2.43, 6.76 and 9.1 MeV in Be^{9*}, and 0., 2.90 and 11.4 MeV in Be^{8*}. The experimental center of mass angular distribution of the inelastically scattered neutron from Be^{9*} (2.43 MeV) was described by a P_6 Legendre expansion. All other reactions were considered to be isotropic in their respective center of mass systems.

The calculation was performed with the AGN-SIGMA[34] multigroup code with 66 groups. Lethargy widths were 0.2 for energies above 10 MeV, and 0.25 for energies below 10 MeV. This introduces a spread in the emergent spectra due to the finite group widths. The threshold spectrum was taken equal to that at 2 MeV, although modified so as not to violate energy conservation. Similarly, the 20 MeV spectrum was taken equal to that at 14.6 MeV. The energy distributions are probably accurate to ±25%.

C. Angular Distributions, Normalized Probabilities

The lab system angular distributions were obtained by appropriately summing the partial distributions of Perkins.[33] The threshold distribution is essentially in the forward direction.

The distributions at 2. and 2.5 MeV were taken equal to that at 3. MeV; those at 5.5 and 7. MeV were taken equal to that at 4. MeV; those at 9. and 11. MeV were taken equal to that at 12. MeV; and that at 20. MeV was taken equal to that at 14.6 MeV. The accuracy of the angular distributions is probably no better than ±20%.

The angular distributions, used in conjunction with the (n,2n) energy distributions, neglect the energy-angle correlation. This is a valid approximation for this reaction for reactor calculations, as has been discussed previously.[35]

IV. OTHER REACTIONS

A. (n,p) Cross Section

This cross section was estimated from the known threshold value and the single measurement at 15.5 MeV given in Ref. 36. The accuracy of this small cross section is probably within a factor of 2.

B. (n,d) Cross Section

This cross section is based in its entirety on the known threshold value and the data between 16.5 and 18.8 MeV reported in Ref. 37. The accuracy is about ±25% for this cross section.

C. (n,t) Cross Section

The cross section for the (n,t) reaction is based on the assumption that all transitions proceed through Li^{7*}(0.477 MeV). This is in agreement with the results of Ref. 38 and 39 but in total disagreement with the data from Ref. 40. The uncertainties in this latter reference, however, are large enough so as to neglect the work.

The cross section was based on the work in Ref. 41, from 13.6 - 14.7 MeV. Above this energy, there is a resonance structure seen in the total cross section reported in Ref. 12 and 14. This was assumed to be due to the (n,t) reaction and is not in conflict with the rapid increase in the cross section above 14.5 MeV seen by Ref. 41. The uncertainty in the cross section is about ±50% at 14 MeV, increasing several times at higher energies.

D. (n,α) Cross Section

The cross section was based on the measurements reported in Ref. 42, 40 and 43 for neutron energies less than 8.6 MeV. It was then artfully interpolated into the three values given at 14 MeV, Refs. 44, 39 and 45, and then smoothly extrapolated to 20. MeV. Note that the measured cross section is to He^6(0. MeV) which beta decays to Li^6; higher states in $He^6 \rightarrow \alpha + 2n$. Below 8.6 MeV, the uncertainty is about ±25%, from 8.6 to 14 MeV being at least ±50%, and being about ±30% at 14 MeV. For higher energies the uncertainty probably reaches a factor of two at 20 MeV.

E. (n,γ) Cross Section

The cross section was assumed to be 1/v below 100 eV with a 2200 m/sec cross section of 9.5 mb. It was then extrapolated linearly on a log-log basis to 0.1 mb at 1 keV, and then held constant at this value up to 20 MeV. Except at thermal where the cross section is known to ±10%, the uncertainty is at least ±100%. Fortunately, the cross section is small.

V. (n,Xγ) CROSS SECTION

Gamma rays in Be^9 are produced by the (n,γ) and the (n,t) reactions. At thermal energies, Ref. 46 quotes gamma ray energies of 0.8535, 2.59, 3.368, 3.444, 5.958 and 6.81 MeV and the corresponding (n,Xγ) cross sections. We have assumed that these energies and their multiplicities are independent of energy, and have used them in conjunction with our (n,γ) cross section to develop this component of the (n,Xγ) cross section. This violates energy conservation as the incident neutron energy is increased. We intentionally used this approach to call attention to the paucity of information. As the incident energy is increased, there are, no doubt, higher levels of ^{10}Be which are excited. Higher levels have not been identified. We could have conserved energy by using energy dependent multiplicities. We chose to emphasize the problem by the presentation used. The component relevant to the (n,t) cross section is in fact equal to the (n,t) cross section since its multiplicity is unity. At thermal energy, the cross section is accurate to about ±10%. At higher energies, the photon energies are not known and the cross section could be off by orders of magnitude. The cross sections is however small.

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5-B-10 1155 LASL,ORNL ORNL-TM-1872(OCT 67) JAN72 D.IRVING,R.LABAUVE(STANDARD B-10)

SUMMARY DOCUMENTATION FOR B-10*

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ABSTRACT

The following neutron data are given for B-10 in the energy range 1.0×10^{-5} eV to 15 MeV;

File 1. General description of data which follow.

File 2. Values of nuclear spin and effective scattering radius only.

File 3. Smooth cross sections for total, free-atom elastic, total inelastic, the inelastic level at 717 keV (MT = 51), the inelastic continuum, (n,d), (n,t), and (n,α). Also data for $\bar{\mu}$, ξ, and γ are included.

File 4. Angular distributions for elastic scattering (expressed as Legendre polynomial coefficients in the center-of-mass system), the first inelastic level, and the inelastic continuum. (The inelastic distributions are given as tabulated functions with the assumption of isotropy in center-of-mass system.)

File 5. Secondary energy distribution for the inelastic continuum (law 9 - evaporation spectrum).

INTRODUCTION

This evaluation for ^{10}B (MAT 1155) is essentially the same as that given for ENDF/B, Version I in MAT 1009 which was performed in October 1967 by D. C. Irving[1] of ORNL. At the CSEWG meeting of May 19-20, 1971, the Standards Subcommittee requested LASL to modify the (n,α) cross sections (MT = 107) of ^{10}B (MAT 1009) below 100 keV to conform to a recent evaluation of Sowerby et al.[2] In carrying out this request, it was also decided to 1) extend the range of modification to 150 keV, and 2) change the elastic scattering cross sections (MT = 2) in the modified energy range, and, of course, 3) change the total cross section to be equal to (MT2 + MT107).

The MAT 1009 evaluation contained 15 datum points from 1.0×10^{-5} eV to 150 keV. As the Sowerby evaluation is based on experimental measurements of the ratio $\sigma_{n,\alpha}(^6Li)/\sigma_{n,\alpha}(^{10}B)$, the modified cross sections were put on the same mesh (30 points) currently in use in the LASL ^6Li (MAT 1115) evaluation. The energy range was also extended to 150 keV as the MAT 1009 data were easier to merge at this point than at 100 keV. Moreover, it was felt that additional points were needed between 100 keV and 150 keV to compare with the ^6Li data.

The (n,α) modified cross sections, as recommended by Sowerby et al.,[2] are given by the formula:

* Work done under the auspices of the United States Atomic Energy Commission

$$\sigma_{n,\alpha}(^{10}B) = \frac{13.736}{\sqrt{E}} - 0.312 - 1.014 \times 10^{-2}\sqrt{E} + \frac{2.809 \times 10^5}{\sqrt{E}\,[(170.3-E)^2 + 2.243 \times 10^4]} \quad (1)$$

with σ in barns and E in keV.

Incidentally, the $\sigma_{n,\alpha}$ data in the old ENDF/B ^{10}B evaluation did not differ greatly from this formula. The largest deviation from formula (1) for MAT 1009 was about 4%. The most significant change was the use of a more descriptive mesh.

This investigation did reveal a need to change the elastic scattering cross section, however. The ENDF/B evaluation was based on 1966 data of Mooring;[3] whereas this modification was based on more recent (1969) data of Asami and Moxon.[4]

FILE 1: GENERAL INFORMATION

A brief summary of these data is given in File 1. The atomic mass for ^{10}B was taken as 10.0130.

FILE 2: RESONANCE INFORMATION

A nuclear spin of 3 and effective scattering radius of 0.399×10^{-12} cm is given in File 2.

FILE 3: SMOOTH CROSS SECTIONS

Below 150 keV:

$\sigma_{elastic}$ - from experimental data of Asami and Moxon[4], with a constant value of 2.2 barns below 100 eV.

$\sigma_{n,\alpha}$ - given by formula (1) (Sowerby et al.[2]).

σ_{total} - $(\sigma_{elastic} + \sigma_{n,\alpha})$.

From 150 to 500 keV:

$\sigma_{elastic}$ - from the smooth curve of Mooring.[3] This agrees with the data of Lane et al.

$\sigma_{n,\alpha}$ - from a smooth curve through the (n,α) data of Mooring[3] and Gibbons,[5] with little weight placed on the data of Cox.[6]

σ_{total} - $(\sigma_{elastic} + \sigma_{n,\alpha})$.

Above 500 keV:

$\sigma_{elastic}$ - $(\sigma_{total} - \sigma_{inelastic} - \sigma_{n,\alpha} - \sigma_{n,d} - \sigma_{(n,t)2\alpha})$.

σ_{total} - from the data displayed in BNL325.[7,8] Some minor adjustments were made to remove spurious wiggles in the elastic cross section above 4 MeV.

$\sigma_{n,\alpha}$ - from the data of Davis[9] increased by 110 mb as suggested by a comparison to the data of Gibbons[6] and Nellis.[10]

$\sigma_{(n,t)2\alpha}$ - from a smooth curve was drawn by eye through the sparse data of Frye,[11] Wyman,[12] and Perkin.[13]

$\sigma_{n,d}$ - a smooth curve was drawn through the Be(d,n) data of Bardes[14] and Siemsson[15] and detailed balance used to obtain $^{10}B(n,d)$ values. These were connected by a straight line to a value at 14 MeV obtained by integration of the data of Valkovic[16] which is slightly higher than that of Ribe.[17]

$\sigma_{inelastic}$ - data from Day[18] on excitation of the first level which agrees with that of Nellis[10] was used to 4.5 MeV. This was connected by a smooth curve to a value at 14 MeV obtained by subtracting (n,d), (n,α), and (n,t) from the nonelastic value of MacGregor.[19]

The (n,n'd)2α reaction was neglected since it is contained for all practical purposes in the inelastic data.

FILE 4: SECONDARY ANGULAR DISTRIBUTIONS

The experimental data for elastic scattering angular distribution is sparse, consisting of a few points between .5 and 2 MeV (BNL400)[20] and one at 14 MeV (reported in Valković[16]). By all rights an optical model should not be valid for boron. However, the calculations of Agee[21] compare beautifully with the experimental data and have been used in the evaluation. The angular distribution was taken to be isotropic below .5 MeV in agreement with BNL400 and the data of Lane et al. (see Mooring).

The secondary angular distribution for inelastic scattering was assumed isotropic in the center-of-mass system.

FILE 5: SECONDARY ENERGY DISTRIBUTIONS

Up to 4.5 MeV, inelastic scattering was assumed to proceed via the first level at .71 MeV. Above 4.5 MeV an evaporation spectrum was used with the temperature as determined by Weinberg and Wigner.[22]

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5-B-11 1160 GE.BNL DFN=49A SEP71 C.COWAN (AWRE DATA MOD 1971)

SUMMARY DOCUMENTATION FOR BORON-11

EVALUATION: Boron-11 was evaluated in September, 1971, by C.L. Cowan from General Electric Company and on temporary assignment at Brookhaven National Laboratory.

PRINCIPAL REFERENCE: The boron-11 evaluation was based upon a transition from the UKAEA data file (material number 49) and the data were modified to conform with the ENDF/B-III format. The cross section data, nuclear parameters and angular scattering distributions for boron-11 are consistent with the recommended values in BNL-325.

SPECIAL CALCULATIONS: Smooth pointwise cross sections for the elastic and capture reactions were calculated by utilizing the Breit-Wigner single level formula and the recommended resonance parameters from BNL-325. The pointwise elastic cross section values were further normalized to the total boron scattering cross section curves in BNL-325.

6-C-12 1165 KAPL KAPL-3099(JUN 66) JAN72 C.LUBITZ ET.AL.(STANDARD TOTAL)

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                    ENDF/B MATERIAL
CARBON=12 KAPL        EVAL=1965  C.LUBITZ, E.SLAGGIE,J.T.REYNOLDS
KAPL-3099(JUNE,1966) DIST=JUL68 REV-JAN72
*        *        *        *        *        *        *
DATA MODIFIED JAN, 1972 TO CONFORM TO ENDF/B-III FORMATS
         *        *        *        *        *        *
THE TOTAL CROSS SECTION WAS MODIFIED JAN. 1972 TO CONFORM TO
THE STANDARD CROSS SECTION RECOMMENDED BY THE CSEWG NORMALIZATION
AND STANDARDS SUBCOMMITTEE.
THE TOTAL X/S IS THAT RECOMMENDED BY N.C.FRANCIS, C.R. LUBITZ,
J.T. REYNODS, C.J. SLAVIK, AND R.G. STIEGLITZ. SEE PAPER GIVEN
AT THE CONF. ON NEUTRON STANDARDS AND FLUX NORMALIZATION
(ANL) OCT 21-23, 1970, PAGE 166.
         *        *        *        *        *        *
THE STANDARD CROSS SECTION IS THE TOTAL CROSS SECTION FOR NEUTRON
ENERGIES UP TO 2.0 MEV
         *        *        *        *        *        *
ABOVE 2.0 MEV THE NEUTRON CROSS SECTIONS ARE THE SAME AS GIVEN
FOR MAT= 1140.
THE ELASTIC SCATTERING CROSS SECTION WAS MODIFIED TO REFLECT
THE NEW TOTAL CROSS SECTION
*        *        *        *        *        *        *
ALSO TOTAL AND ELASTIC SCATTERING MODIFIED  JUNE 1970
*        *        *        *        *        *        *
THIS DATA SET IS BASED ON DATA IN MAT=1010
THE TOTAL AND ELASTIC SCATTERING MODIFIED FOR NEUTRON ENERGIES
LESS THAN    5.0 MEV.
*        *        *        *        *        *        *
ABOVE 5.0 MEV THE ELASTIC SCATTERING AND THE TOTAL CROSS SECTIONS
 WERE BASED LARGELY ON THE EVALUATION REPORTED IN THE PHYS. REV.
 176,1213,1968.
*        *        *        *        *        *        *


*        *        *        *        *        *        *
CARBON=12 EVALUATED CROSS SECTIONS (KAPL-1965)
TOTAL,ELASTIC,INELASTIC,N-ALPHA,AND N-3ALPHA-NPRIME CROSS SECTIONS
  AND ELASTIC SCATTERING LEGENDRE MOMENTS
REFERENCE-=KAPL-3099,C-12 FAST NEUTRON CROSS SECTIONS AND LEGENDRE
  MOMENTS BELOW 15 MEV,JUNE 30,1966,E.L. SLAGGIE AND J.T. REYNOLDS
N-GAMMA CROSS SECTION PREPARED JUNE,1967. CROSS SECTION IS 1/V
  WITH A THERMAL ENERGY VALUE OF 3.4 MB.
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7-N-14 1133 LASL TO BE PUBL. JAN71 P.G.YOUNG,D.G.FOSTER,JR

SUMMARY DOCUMENTATION FOR NITROGEN*

P. G. Young and D. G. Foster, Jr.

Los Alamos Scientific Laboratory

ABSTRACT

A complete evaluation is given of the neutron and photon-production cross sections of nitrogen (assumed throughout to consist only of ^{14}N) from 10^{-5} eV to 20 MeV. For a full description, see LA-4725. The following files are included:

File 1. Summary of the basis of the evaluation, including all of the principal references used and tables of the Q-values corresponding to each MT-number.

File 2. Effective scattering radius of 8.9014 fm to yield a potential-scattering cross section of 9.957 b.

File 3. Smooth total cross section, and smooth cross sections for elastic scattering, inelastic scattering, and the (n,γ), (n,p), (n,d), (n,t), (n,α), $(n,2n)$, and $(n,2\alpha)$ reactions. The $(n,n'p)$ and $(n,n'\alpha)$ cross sections are included with the (n,n') cross sections, using flags to indicate the mode of decay. Excitation of the high-lying levels is grouped into 20 discrete bands instead of a continuum, to permit approximately correct calculation of the energy-angle relations in the lab system.

File 4. Secondary-neutron angular distributions, given as Legendre coefficients in the C.M. system for one emitted neutron and as normalized pointwise distributions in the lab system for the $(n,2n)$ reaction.

File 5. Secondary-neutron spectrum for the $(n,2n)$ reaction in the lab system, obtained from the Jacobian for a three-body reaction assuming isotropy in the C.M. system.

File 12. Photon multiplicities for the (n,γ) reaction.

File 13. Photon-production cross sections for $(n,x\gamma)$ reactions, consistent with the excitation cross sections in File 3.

File 14. Angular distributions of photons from capture and $(n,x\gamma)$ transitions. Four of these are anisotropic.

NEUTRON CROSS SECTIONS

MAT #1133 contains an entirely new evaluation of the neutron and photon-production cross sections of nitrogen over the energy range from 10^{-5} eV to 20 MeV. Since ^{15}N constitutes only 0.37% of natural nitrogen and has no unusually large cross sections in the eV region, nitrogen was

* Work supported by the Defense Nuclear Agency under Subtask PC102

treated as pure ^{14}N throughout the evaluation. To the best of our knowledge, all data available up to the fall of 1970 were considered, although only about 60 of the most important references are listed in this summary, which is intended to accompany the data file distributed as Mat #1133 under the ENDF/B system. The principal processes considered were (n,γ), (n,n), (n,n'), (n,p), (n,d), (n,t), (n,α), (n,2n), (n,n'p), and (n,n'α). A full report is in preparation and will be distributed as LA-4725.

The evaluated total cross section was determined entirely from experimental measurements, relying heavily on the post-1967 time-of-flight data (Ca70, He70, Fo71) in the MeV region, which are consistent with each other to better than 1 percent. These were used to correct the energy scales and absolute values of older measurements (Bi59, Bi62, Hi52, Hu61) in the high keV range, which extend down to 10 keV. Below 10 keV the data of Melkonian (Me49) between 1 and 79 eV were fitted to determine the free-atom cross section, assuming a constant scattering cross section and a reaction cross section varying as 1/v from an evaluated 2200-m/sec value (Ba49, Co48, Cu51, Ha61, Ju63) of 1.894 b. This fit was extrapolated to 10^{-5} eV, and joined to the data above 10 keV by a polynomial fit. Data in the sharp peaks were smoothed by single-level Breit-Wigner fits, assuming a linear background. Between peaks a sliding polynomial fit was used for smoothing. The estimated accuracy of the total cross section ranges from 5% at 10^{-5} eV to 1% above 0.5 MeV.

Below about 10 MeV the elastic-scattering cross section was determined by summing the partial cross sections, which were determined mainly from measurements, and subtracting the result from the total cross section. Above 9 MeV, however, many new levels in ^{14}N become available for inelastic scattering, most of which decay by proton emission and hence cannot be detected by (n,xγ) measurements. Because of the resulting uncertainty in these (n,n') cross sections to particle-unstable states, above 10 MeV the elastic cross section was determined first (Ba63, Ba67, Be67, Bo68, Ch61, Lu67, Ne71, Sm54, St61), and the nonelastic cross section obtained by subtraction from the total. The remaining reaction cross sections above 10 MeV were evaluated separately, and the balance of the nonelastic cross section was assigned to the (n,n'x) channels. In File 3 the charged-particle decays are flagged by placing the MT number of the overall reaction [MT = 28 for (n,n'p), MT = 22 for (n,n'α)] in the fourth field of the TAB1 record and the Q-value of the reaction in the first field.

For several years it has been observed (Di69, St69) that the measured partial cross sections between 6 and 9 MeV add up to less than the total cross section. When this evaluation was originally prepared the unpublished preliminary small-angle elastic-scattering results from Edgewood Arsenal (Bu71) were used to deduce the largest possible elastic cross sections from the Livermore data (Ba63), and the reaction measurements were "stretched" to the upper limit of their error bars. Wherever these measures did not suffice to close the gap the nonelastic results were adopted as correct, a choice which has been supported by data (Ne71, Pe71) which became available after the evaluation had been completed.

The angular distributions for elastic scattering below 8 MeV were determined from a single-level resonance-theory analysis, which incorporated the resonance parameters (Aj68, Aj70) used in smoothing the total cross sections. With the parameters of 35 resonances fixed, the s- and p-wave potential phase shifts were adjusted to fit the available elastic angular distributions (Ba67, Bo57, Ch61, Fo55, Fo66, Ph61), and the evaluated distributions were regenerated from the complete set of phase shifts. From 8 to 15 MeV the angular distributions were taken from smooth curves through the Legendre coefficients obtained from fits to the measured (Ba63, Ba67, Be67, Ch61, Lu67, Ne71, St61) distributions, and these were extended to 20 MeV using optical-model parameters which fitted the 14-MeV measurements.

The angular distributions for inelastic scattering to the 12 lowest discrete levels were taken almost entirely from (p,p') measurements (Do64, Ha70, Od60, and neutron data of Ba63), relying on an equivalence theorem derived from charge symmetry by Anderson et al. (An67, Lu66). For higher excitation energies isotropic distributions have been assumed in the center-of-mass system. Instead of describing these by continuum angular distributions and secondary spectra in Files 4 and 5, however, these channels have been grouped into bands of excitation energy and treated as discrete levels in File 3, so that the pronounced anisotropy and nonuniform spectral distribution induced by the transformation to the laboratory system can be calculated as if each band corresponded to a single excited state. The Q-values for the centers of these bands are given in File 1 along with the discrete levels.

The cross sections for the (n,p_0), (n,d_0), (n,t_0), and (n,α_0) channels (Ba68, Bo51, Ca57, Fe67, Ga59, Jo50, Le68, Li52, Li67, Ma68, Mi68, Re67, Sc66, Za63) and their inverses (Be63, Ch61, Gi58, Wo67), and for the $(n,2\alpha)$ reaction (Li52, Mo67) have been measured directly for at least a few energies, and the (n,2n) cross section has been measured (Bo65, Br61, Cs67, Fe60, Go65, Pr60) by detecting the positron decay of ^{13}N, so the evaluated cross sections for these reactions were taken directly from experiment. The cross sections to excited states for both inelastic scattering and the $(n,x\gamma)$ reactions were deduced primarily from photon-production measurements (Bo59, Bu69, Cl69, Co68, Di69, En67, Ha59, Ny69, Or69), using decay schemes (Aj68, Aj70) which in most cases were based largely on measurements made with the appropriate charged particles. In several instances the measurements had to be supplemented with Hauser-Feshbach or nuclear-temperature calculations, especially above 14 MeV. In particular, Hauser-Feshbach calculations were used extensively to interpolate excitation functions between measured points.

Especially for the reactions which produce charged particles, there are a number of direct measurements (An64, Fe67, Ga59, Ha59, Re67, Sc66, Sm54, Za63) of cross sections to excited states. In almost all cases these were found to be in acceptable agreement with the photon-production measurements. Excitation cross sections are given in File 3 for transitions to 12 discrete levels and 20 bands in ^{14}N, 4 levels in ^{14}C, 3 levels in ^{13}C, one level in ^{12}C, and 10 levels in ^{11}B.

There are no measurements available of the angular distribution or spectrum of neutrons from the (n,2n) reaction. Accordingly, the distributions given in Files 4 and 5 are based on the assumption of isotropic emission in the C. M. system, and are proportional to the Jacobian for the three-body transformation to the laboratory system.

PHOTON-PRODUCTION CROSS SECTIONS

The evaluated radiative-capture cross section at low energies was based on a single measurement by Jurney (Ju63) with thermal neutrons; even at 2200 m/sec it is much smaller than the (n,p) cross section. The multiplicities for thermal-neutron capture (Gr68, Jo69, Mo62, Th67) are given in File 12, with isotropic angular distributions in File 14. Because direct capture offers a mechanism for producing gamma-ray energies in excess of 20 MeV with 14-MeV neutrons, we have included an explicit cross section for the (n,γ_0) channel in the MeV region. Since there is as yet no means in the ENDF/B formats of flagging "primary" transitions, the energy variation of the ground-state gamma ray in the MeV region has been approximated by the phasing-in and -out of fictitious gamma rays of successively higher energy. The data were taken from ^{14}N (p,γ) measurements by Kuan et at. (Ku70), in the region of the inverse photonuclear giant resonance, since this reaction is expected to populate isotopic-spin states analogous to those in ^{14}N (n,γ). The strong anisotropy of (n,γ_0) emission found by Kuan et al. is given in File 14.

In the first section it was pointed out that most of the excitation cross sections for excited states were deduced from photon-production measurements. Consequently, although the cross sections in File 13 were regenerated from File 3 by use of the appropriate decay schemes, they are in general at least as accurate as the excitation cross sections, because they were chosen so as to reproduce the gamma-ray measurements.

The angular distributions of nine intense gamma rays have been measured by Morgan et al. (Mo63, Mo64) at 14 MeV. Legendre fits to these data are consistent with isotropic emission for all except three gamma rays; of these, two are from $(n,n'\gamma)$ transitions and one from $(n,d\gamma)$. Thus, the only anisotropic photon angular distributions in File 14 are for MT = 4, 102, and 104. In the absence of other measurements, the $(n,x\gamma)$ anisotropies have been assumed to rise linearly from threshold to the measured value, and to remain constant from there to 20 MeV.

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8-0-16 1134 LASL TO BE PUBL. AUG71 P.G.YOUNG,D.G.FOSTER,JR

SUMMARY DOCUMENTATION FOR OXYGEN *

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ABSTRACT

A preliminary evaluation of the neutron and photon-production cross sections of oxygen (treated throughout as if it were 100% ^{16}O) is presented covering the range 10^{-5}eV to 20 MeV. Parts of the 1965 KAPL evaluation have been retained unchanged, parts have been revised, and some of the evaluation is entirely new. The "window" in the total cross section at 2.35 MeV is shallower and broader than in the 1965 evaluation, and comes at a slightly lower energy. The total cross section near 14 MeV is about 15% higher than before, and the integrated elastic-scattering cross section above 10 MeV is about 50% higher. The inelastic cross section is smaller by a factor of two between 7 and 12 MeV, but rises to the old value at 14 MeV. A more complete description is given in LA-4780. The following files are included, in ENDF/B-III format:

File 1. Summary of the basis of the evaluation, including all of the principal references and tables of the Q-values corresponding to particular MT-numbers.

File 2. Effective scattering radius of 5.429 fm, to yield a zero-energy scattering cross section of 3.704 b. No resolved-resonance parameters are given.

File 3. Smooth total cross section, and smooth cross sections for elastic scattering, inelastic scattering, and the (n,γ), (n,p), (n,d) and (n,α) reactions. The (n,n'p) and (n,n'α) cross sections are included in the (n,n') files, using flags to indicate proton or alpha-particle decay of the excited state. Twenty discrete excited states in ^{16}O and three in ^{13}C are treated explicitly. Excited states in ^{16}O above 13 MeV are grouped into 19 discrete bands of excitation energy in order to preserve the energy-angle relationships in the laboratory system.

File 4. Secondary-neutron angular distributions for elastic and inelastic scattering, given as Legendre coefficients in the C.M. system. The inelastic distributions are all taken as isotropic in the C.M. system.

File 12. Photon multiplicities for the (n,γ) reaction.

File 13. Photon-production cross sections for (n,xγ) reactions, consistent with the excitation cross sections in File 3.

File 14. Photon angular distributions, all taken as isotropic.

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INTRODUCTION

MAT 1134 contains a preliminary evaluation of the neutron and photon-production cross sections of oxygen. The 0.23% of $^{17,18}O$ has been ignored throughout, but it should be emphasized that the minimum cross section given in the "window" at 2.35 MeV is the cross section of natural oxygen. Parts of this evaluation are either copied from the 1965 evaluation of Slaggie and Reynolds (S165) or are only minor revisions thereof, wheras other parts are completely new. Explicit gamma-ray production files have been added. The only processes treated are elastic and inelastic scattering and the (n,γ), (n,p), (n,d), (n,α), (n,n'p), and (n,n'α) reactions and the gamma-ray decay of some of the resulting excited states. A full report on the present evaluation is in preparation and will be distributed as LA-4780. This evaluation has passed Phase I review for ENDF/B-III, but further work on it is planned for the near future.

NEUTRON CROSS SECTIONS

The evaluated total cross section is entirely new. Above 0.7 MeV it is based entirely on post-1967 references, and below 0.7 MeV entirely on much older work. The 1965 evaluation (S165) of the total cross section above 4 MeV was based on the work of Fossan et al. (Fo61). The recent Hanford (Fo71a) and NBS (Sc71) time-of-flight measurements, which agree with each other within 1%, suggest a substantially higher total cross section above 9 MeV, with the discrepancy reaching about 15% by 14 MeV. The recent Karlsruhe time-of-flight measurement (Ci68), when recorrected for residual dead-time errors using a correction function previouly deduced for nitrogen and aluminum, likewise agrees with the more recent measurements within about 1%. When suitably corrected for resolution, the three time-of-flight measurements and the most recent Oak Ridge measurement (Fo71b), which all used different oxygen-bearing compounds as samples, agree on the minimum cross section at 2.35 MeV within ± 10 mb. This general agreement was taken as justification for discarding the preliminary results from Columbia (Ka71) (which were 50% lower), as well as the older Wisconsin work (Fo61). Accordingly, the cross section between 0.7 and 12 MeV was taken from the NBS work, with inserts of normalized Karlsruhe data where necessary to preserve the resolution, and with inserts of resolution-corrected Oak Ridge data (Fo70) for the very narrow resonances below 4 MeV. Above 12 MeV a composite of the Karlsruhe and NBS results was used. This approach suffers the disadvantage of losing the highest available resolution at many energies, but Fossan's work will have to be corrected in both energy and absolute cross section before it can be used to replace the normalized Karlsruhe data.

The total cross section at very low energies was taken from a weighted average of three old measurements (Ad49, Jo48, Me49), using the results of Okazaki (Ok55) to correct for the tail of the 442-keV resonance. The result is a zero-energy scattering cross section of 3.704 b (including 0.038 b from the tail of the first resonance). The radiative-capture cross section contributes an additional component which varies as 1/v from a 2200-m/sec value of 232 μb (Ju64). The 442-keV resonance itself was taken from Okazaki (Ok55), using a linear background to join it smoothly to the low-energy data on one side and the time-of-flight data on the other side. The composite data were smoothed by approximate single-level Breit-Wigner fits to the sharp resonances and by sliding polynomial fits between resonances. The absolute accuracy is estimated as 4% below the first resonance and 1% at most energies above the resonance (with due allowance for resolution).

The integrated cross section for elastic scattering up to 6 MeV was obtained by subtracting the small (n,α) cross section from the evaluated total cross section. From 6 to 11 MeV, all the remaining constituents of the non-elastic cross section were evaluated separately, relying heavily on gamma-ray production measurements for the cross sections to the excited states, and the elastic cross section again obtained by subtraction from the total. Between 11 and 14 MeV the emphasis was gradually reversed, so that the elastic cross section near 14 MeV was determined from the actual measurements (Ba63, Be67, Ch61, Mc66, Ne71), and the nonelastic determined by subtraction. The difference between the total cross section and the sum of the measured partial cross sections was assigned entirely to the (n,n') cross section, which will be discussed below. The net result is an elastic cross section which rises gradually above the 1965 evaluation (Sl65) until it is approximately 50% greater at 15 MeV, where the older evaluation ended.

In order to extend the elastic cross section to 20 MeV, the parameters of a spherical local optical model were fitted to the angular distribution measured near 14 MeV. Then the depth of the real potential in the model was varied so as to reproduce the heavily-smoothed total cross section out to 20 MeV. The angular distribution of elastic scattering and the total nonelastic cross sections which resulted from these calculations were adopted in the evaluation, and the integrated elastic cross section was obtained by subtracting the smooth nonelastic cross section from the fluctuating total cross section.

Measured photon-production cross sections (Bu71, Cl69, Di70, Dr70, En67, Mc66, Ny70, Or70), together with the level-decay scheme of ^{16}O (Aj71), were used to estimate the (n,n') cross sections to the 6.13, 6.92, 7.12, 8.87, and 11.08 MeV levels in ^{16}O from threshold to 15-MeV, and the evaluated curves were extrapolated to 20 MeV using suitably-normalized compound-nucleus reaction-theory calculations made with the code COMNUC (Du71). The (n,n') excitation cross sections for 15 additional levels with $E_x < 13$ MeV, for which no measurements are available, were also estimated from these calculations using the same normalization as was required for the photon-emitting levels.

Although the (n,n'α) threshold is 7.61 MeV, selection rules and the unavailability of levels in ^{12}C to circumvent the selection rules prevent significant alpha-particle decay of the excited states of ^{16}O until $E_x > 9$ MeV, and the gamma-ray production measurements show that some levels still decay preferentially by photon emission up to $E_x \sim 11$ MeV. Those levels which decay by alpha-particle emission have been flagged in File 3 to indicate the mode of decay, but are retained in the inelastic-scattering records instead of being assigned to MT = 22. The resulting cross section for alpha-particle production is substantially greater than the direct (n,α) cross section, and is in reasonable agreement with total alpha-production measurements (Bo66, Da68, Li52).

In the 1965 KAPL evaluation, the (n,n'α) cross section was included in the (n,α) file; consequently, the present (n,α) cross section is substantially less than the KAPL (n,α). The inclusion of the (n,n'α) cross section in our (n,n') files causes a rapid increase in our total inelastic cross section above 13 MeV, with the result that our total inelastic cross section is in good agreement with the KAPL evaluation at 14 MeV. At lower neutron energies, however, our evaluated (n,n') cross sections are based upon (n,n'γ) measurements that are roughly a factor of two lower than the older measurements used in the KAPL work.

For excitation energies greater than 13 MeV in ^{16}O, we have assumed that all levels decay by charged-particle emission. Since little is known about the level scheme in this range, we have arbitrarily divided the remaining energy range into 19 bands of excitation energy, and distributed among them the inelastic cross section which does not go to the 20 discrete levels. The distribution was made according to an evaporation model with a temperature of 2 MeV. The use of bands of excitation energy in File 3 instead of continua in Files 4 and 5 permits the energy-angle relationships in the laboratory system to be calculated, which is important for a target nucleus as light as ^{16}O. Two of the highest bands are flagged as proton emitters and the remainder as alpha emitters; the possibility of neutron emission has been ignored, since the (n,2n) cross section is less than 3 mb at neutron energies below 20 MeV (Br61). Most of the (n,n') cross section goes to levels with E_x < 13 MeV at neutron energies below ~ 17 MeV.

The evaluated (n,p) cross section up to 15 MeV was copied from the 1965 evaluation, and extended to 20 MeV with the available data (Bo66, De62, Ma54, Se62). The (n,d) cross section was calculated from compound-nucleus theory, and normalized to Lillie's measurement (Li52) at 14 MeV. The (n,α_0) cross section was copied from Sl65 up to 6.3 MeV and extended to 20 MeV using the available direct measurements (Da63, Da68, Ma68, Mc66a, Si68). The (n,α) cross section to the first three excited states in ^{13}C was taken from direct (Da63) and photon-production (Bu71, Cl69, Di70, En67, Mc66, Ny70, Or70) measurements below 15 MeV, and extended to 20 MeV using the results of Sick et al. (Si68).

The angular distributions of elastic scattering in File 4 were copied from the 1965 evaluation up to 5 MeV. From 5 to 14 MeV, smooth curves through the coefficients obtained from Legendre fits to the available data (Ba63, Be67, Ch61, Mc66, Ne71, Ph61) were used. Above 14 MeV the coefficients were taken from the optical-model calculations described above, which was also used to determine the total nonelastic cross section. Wherever necessary the data were augmented with synthetic points at 0^o in order to force compliance with Wick's limit. The inelastic angular distributions were all taken as isotropic in the C.M. system, although the (n,n') distributions to the lowest states are known to be anisotropic (Ba63, Mc66) near 14 MeV.

PHOTON-PRODUCTION CROSS SECTIONS

The cross section for radiative capture was assumed to vary as 1/v from the 2200-m/sec value of 232 μb (Ju64) over the entire energy range. The 2200-m/sec photon spectrum is based on measurments by Jurney (Ju71) and is assumed to hold at all energies. The $(n,n'\gamma)$ cross sections in File 13 are consistent at all neutron energies with the level-excitation cross sections in File 3, using the adopted decay scheme for ^{16}O. As noted above, the evaluations in File 3 were based primarily on the $(n,n'\gamma)$ measurements (Bu71, Cl69, Di70, Dr70, En67, Mc66, Ny70, Or70), supplemented by compound-nucleus calculations above 15 MeV. The first excited state in ^{16}O at 6.052 MeV decays only by internal-pair creation, which cannot be flagged under the existing ENDF formats. Accordingly, File 13 shows the two 0.51-MeV annihilation gamma rays from the positron but the kinetic energy of the electron and positron is simply lost.

The $(n,\alpha\gamma)$ cross sections in File 13, which were reconstituted from the (n,α) level-excitation cross sections, are based mainly on $(n,\alpha\gamma)$ measurements, as noted earlier. The $(n,p\gamma)$ cross sections all have E_γ < 0.4 MeV and were obtained by crudely dividing the total (n,p) cross section among the four particle-stable levels in ^{16}N, assuming that the cross section to each is proportional to (2J+1), where J is the total angular momentum of the state. The $(n,n'\alpha\gamma)$ cross section for the 4.439-MeV gamma ray from ^{12}C was obtained by crudely dividing the available $(n,n'\alpha)$ cross sections given under MT = 56-89 in File 3 among the states in ^{12}C that can be formed by alpha emission. The resulting curve was adjusted slightly to produce agreement with $(n,x\gamma)$ measurements near 14 MeV.

All secondary gamma rays are assumed in the evaluation to have isotropic angular distributions.

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EVALUATION OF SODIUM-23 NEUTRON DATA FOR THE ENDF/B VERSION III FILE*

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I. INTRODUCTION

This report describes the evaluation of neutron cross sections of Na-23, material number 1156, for the ENDF/B File. Cross sections were evaluated between 10^{-5} eV and 15 MeV. Experimental data available up to March 1971 were included in the evaluation.

Since the evaluation of sodium neutron cross sections[1] for ENDF/B Version I, significant new measurements have become available for the total, inelastic for the 0.44 MeV level. The new data improved the magnitude of the resolved level inelastic scattering up to 8.5 MeV, and the accuracy of elastic angular distributions above 1.5 MeV.

II. TOTAL CROSS SECTION

The total cross section of sodium has been re-evaluated for the ENDF/B library in the neutron energy range from 100 eV to 15 MeV. The measurement of the total cross section for neutron energies above 600 eV and below 40 keV at the Nevis Laboratory, Columbia University[2] verifies a spin assignment of J=1 for the 2.85 keV resonance and a neutron width of about 410 eV. The data indicates that the width of the resonance is wider than the earlier measurements by Garg[3], and more in agreement with the measurements of Moxon[4] and Lynn[5]. The peak value of the resonance is within the statistical uncertainty of the theoretical value, which is 380 barns for a resonance with J=1.

Resonance parameters are given in Table 1. Yamamuro's[6] measured value of 0.47 eV for Γ_γ of the 2.85 keV resonance has been used in the present evaluation. Parameters for resonances at 7.53, 35.4, 53.0,

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114.7, 129.5, and 139.1 keV were estimated from data by Moxon[4], Hockenbury[7], and Ribon[8] with particular emphasis on the capture areas measured by Hockenbury[7]. The parameters for the 53.0 keV resonance, for instance, are Moxon's values with Hockenbury's $\Gamma\gamma$ data.

The scattering radius was chosen to provide a good agreement between calculation fo the 2.85 keV resonance at energies above the resonance with measured data from the Nevis Laboratory[2]. Background cross sections are given in File 3 to improve agreement between calculated and measured data below 1.50 keV. The resolved resonance range is defined to be from 600 eV to 150 keV. Below 600 eV the total cross section is based on the data of Columbia[2] and of Joki[9]. The experimental data[2] near the 2.85 keV resonance is shown together with the evaluated values in Figure 1.

The total cross section evaluation between 150 keV to 520 keV is based primarily on measurements by Whalen and Smith[10] and Cierjacks[11]. The results are shown in Figure 2. Above 520 keV total cross sections measured by Stoler[12] and Cierjacks[11] have been used for the evaluation. These two measurements are in good agreement in both magnitude and energy resolution.

Comparison of these two data sets are shown in Figures 3 and 4. The Version I (retained for Version II) data are also shown in Figures 3 and 4 in comparison with the Version III evaluation. Generally, the data by Cierjacks are in 4-5% agreement with Stoler's data below the neutron energy of 1.2 MeV, and in a good agreement (2%) near the peaks of resonances in the energy range between 1.2 MeV and 2.5 MeV. In the same energy range the two data sets, however, differ significantly (10%) in the valleys between major resonances, with corrected Cierjacks data being considerably lower than his earlier values. Evaluation in the Version III in the energy range above 2.5 MeV up to 15 MeV was primarily determined by upper limits of Cierjacks data with some weighing of Stoler's data.

III. INELASTIC SCATTERING CROSS SECTION

Total inelastic scattering cross sections are extensively revised and updated relative to the Version I data of sodium. In the present evaluation there are total eighteen resolved levels for inelastic scattering. The inelastic levels in the file 3 are 0.44 MeV, 2.08 MeV, 2.64 MeV, 2.705 MeV, 2.393 MeV, 2.98 MeV, 3.68 MeV, 3.88 MeV (doublet), 4.43 MeV, 4.77 MeV, 5.38 MeV, 5.53 MeV, 5.76 MeV (a triplet), 5.95 MeV (a doublet), 6.08 MeV (a doublet), 6.27 MeV, 7.11 MeV and 7.79 MeV.

For the levels above 7.79 MeV, inelastic scattering cross section is represented as continuum data.

For the 0.44 MeV level, the high resolution data shown in Figure 5 of Perey[13], which have been normalized to an average of the previous measurements by Chien[14] and Towle[15], have been included up to 2.0 MeV. The thirteen resolved levels from 2.08 to 5.59 MeV are primarily determined by using the recent measurements by Perey and Kinney[16] and those of Fasoli[17] which lead to a complete re-evaluation of the ENDF/B data above 4.0 MeV to 8.5 MeV. The measured doublet at 2.671 MeV has been split into two levels, one at 2.64 MeV $\left(\frac{1^-}{2}\right)$ and at 2.705 MeV $\left(\frac{9^+}{2}\right)$, according to calculated results by Perey[18].

The inelastic scattering cross sections for the four resolved levels above 6 MeV are not based on resolved experimental data. Instead, peak inelastic scattering cross sections for 6.72, 7.11, and 7.79 MeV levels were estimated to be 0.06b, and that for the doublet at 6.08 MeV to be 0.08b. The continuum data for levels above 7.79 MeV were then obtained as the difference between the estimated total inelastic scattering cross sections above 7.79 MeV and the sum of all resolved level data which were extrapolated above 7.79 MeV.

The total inelastic scattering cross sections in the present evaluation are 0.907 barn between the neutron energy of 6 and 7 MeV. The evaporation theory estimate of Williamson[19] at 7.2 MeV is 0.93b, which is in fair agreement with the evaluation. Above 8.5 MeV, the continuum data and shapes of four resolved inelastic scattering levels (6.08 MeV, 6.27 MeV, 7.11 MeV and 7.79 MeV) have been determined in a way so that the total inelastic scattering cross section is approximately linear between 9 and 15 MeV with 0.89b and 0.60b at respective energy.

IV. ANGULAR DISTRIBUTIONS FOR ELASTIC AND INELASTIC SCATTERING

Angular distributions for all resolved and unresolved levels for inelastic scattering of sodium represented to be isotropic in the Version III file. Measurements of inelastic scattering angular distributions by Fasoli[17] and Perey[16] do not indicate significant deviations from isotropic scattering.

Angular distributions for elastic scattering have been revised by Perey's data[16] in the energy range above 4 MeV to 8.5 MeV. In this energy range the angular distributions are represented by 10th order legendre polynominal fits to the experimental data. Angular distributions above 10 MeV were obtained from the legendre polynominal expansion coefficients by Campbell[20] which were based on theoretical results by Agee and Rosen[21].

V. CAPTURE CROSS SECTION

The sodium capture cross section between 100 eV and 200 keV is based primarily on the resonance parameter evaluation (See Section I) and in agreement with the capture areas measured by Hockenbury[7]. The radiation width for the 2.85 keV resonance, which dominates Na capture cross section, is 0.47 eV[6] compared to 0.33 eV for the ENDF/B Version 1 evaluation. Integral testing[22] of this capture cross section change of sodium indicated that the eigenvalue calculation of a fast reactor system with a power reactor spectrum is not significantly affected (0.01% Δk change for $\Gamma\gamma = 0.47$ eV compared to using $\Gamma\gamma = 0.33$ eV).

Above 200 keV and below 100 eV, the capture cross section of the Version I sodium evaluation [1] was retained for the present evaluation.

VI. ELASTIC SCATTERING

The elastic scattering cross section was obtained by subtracting the total nonelastic cross section, computed as a sum of its separately evaluated partial cross sections, from the evaluated total cross section. The scattering cross section has the similar structure as the total cross section particularly between 1 keV and about 2 MeV, the evaluated elastic scattering cross section averaged with experimental energy resolution were found to be within the experimental measurement uncertainties of Perey's elastic data at 5.44 ± 0.17, 6.37 ± 0.13, 7.60 ± 0.10, 8.52 ± 0.08 MeV. The evaluated elastic scattering cross section as well as the measured data by Perey has a minimum value of 0.6b near 8.5 MeV, and tends to increase to 0.8b at 15 MeV.

VII. THRESHHOLD CROSS SECTIONS

The (n, 2n) cross section was re-evaluated based on measurements indicating a lower cross section than the previous evaluation. The evaluated (n, 2n) cross section in the Version 3 file agree closely with Menlove's measurements[23] and calculations by Pearlstein[24]. The (n, p) and (n, α) cross secitons of the previous evaluation[1] was retained in the Version III file.

VIII. SOME COMMENTS ON DATA UNCERTAINTIES AND DATA TESTING

Present estimates of uncertainties on sodium-23 neutron cross sections are given in Table II. Results of calculated integral parameters with the new sodium data for a typical fast power reactor benchmark critical assembly, ZPPR-2, are compared with experiments and with calculations using Version I sodium data. Due to the simplicity of the cylindrical model, only relative magnitudes are meaningful, but not absolute magnitudes which are given in Table II.

Eigenvalue, central reaction ratios, central material worths other than sodium are not significantly affected by the choice of sodium data, but the calculated central sodium worth, however, is about

9% larger in absolute magnitude using the new sodium data. This 9% difference is due to a 4% change in the capture component and a 5% change in the moderation component of the material worth.

TABLE I. RESONANCE PARAMETERS IN ENDF/B VERSION 3 SODIUM EVALUATION

Resonance Energy, keV	J	l	Γn,eV	Γγ, eV
2.85	1	0	410	0.47
7.53	1	1	0.012	1.5
35.4	3	1	0.86	0.76
53.0	2	1	1200	1.48
114.7	2	0	11.0	2.72
129.5	3	1	0.374	1.5
139.1	2	1	3.33	1.5

Table II Summary of Na-23 Data Uncertainties and Data Testings

Estimates of Sodium Neutron Data Uncertainties

$\Gamma_\gamma(E_o$ = 2.85 KeV) = 0.47 ev ± 30%

$\Gamma_n(E_o$ = 2.85 KeV) = 410 ev ± 10%

σ_t: ±3-5% over entire energy range

σ_{in}: ±10% below 2 MeV, 10-15% above 2 MeV, ±30% above 8 MeV

$\sigma_{n\gamma}$: ±20% where capture cross section is significant

σ_{np}: ±30% between 5 to 15 MeV

$\sigma_{n\alpha}$: ±20% below 8.5 MeV, $\left(^{+5\%}_{-50\%}\right)$ above 8.5 MeV, $\left(^{+50\%}_{-10\%}\right)$ above 11 MeV

σ_{n2n}: ±50% below 15 MeV

Comparison of Calculations[a] and Experiment[a] for ZPPR-2

	Experiment		Version 1 Na	New Na
Eigenvalue	1.00		0.997	0.996
Central Reaction Ratios				
f^{235}/f^{239}	1.067	± .016	1.083	1.083
f^{238}/f^{239}	0.0214	± .0004	0.0228	0.0228
f^{240}/f^{239}	0.182	± .003	0.188	0.188
c^{238}/f^{239}			0.155	0.155
Material Worths (Ih/Kg)				
∿ core center				
Na-23	-5.1	± .44	-4.09	-4.43
Pu-239	118.4	± .79	130.24	130.24
U-238	-10.5		-7.85	-7.8
Ta-181	-50.3	± 1.0	-41.9	-41.4
B-10	-2237	± 41	-2193	-2176
Core-Radial Blanket Interface				
Na-23	3.88		3.34	3.35
Pu-239	25.5		24.7	24.7
B-10	-358		-344	-345

a: Details of a calculational model and data used in calculations are given in reference 22. Experimental data from reference 25.

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SUMMARY DOCUMENTATION FOR SODIUM GAMMA-RAY PRODUCTION CROSS SECTIONS

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Sodium Photon Production Evaluation - ORNL August 1971

The previous photon production evaluation for sodium by M. K. Drake et al., Mat 5001, Ref. 1, was performed in 1967. Since then much new experimental information has become available to warrant a revision of this evaluation in the lower energy region. This reevaluation, Mat 1156, was undertaken to be compatible in format with a reevaluation of the neutron cross sections concurrently performed at Ward. Because much data were available and due to the formats chosen, these photon production files should be quite reliable up to 8 MeV incident neutron energy. Above that energy, we have borrowed from Mat 5001 to extend the files up to 15 MeV.

Up to 8 MeV neutron capture and inelastic scattering dominate photon production in sodium. Although (n,p) and (n,alpha) reactions have low thresholds, the cross sections are small below 8 MeV and calculations indicate that mostly the ground states are populated. Therefore we have neglected photon production arising from (n,p) and (n,alpha) reactions.

Above 8 MeV the energy distribution for photons for MT=91 was from Mat 5001.

File 12

MT=51 to 63

Transition probabilities are rather well established for these levels and the values adopted follow the review of Ref. 2. MT=58 represents a doublet of levels having the same spin but opposite parity. Calculations indicate that the cross sections to each member are equal to within a few per cent. The transition probabilities for MT=58 are the average of those for the two levels.

MT=64 to 68

Each one of these MT numbers represent groups of levels. No experimental data are available to correctly describe the transition probabilities for MT=64 to 68. For MT=64 and 65 equal probability for decay to the ground state and first excited state have been assigned. For MT=66 to 68 we have given the average branching ratio for 6 levels seen from 6.9 to 7.1 MeV in Ref. 3. These assignments for MT=64 to 68 should not underestimate the amount of penetrating photons for these levels.

MT=91

This is adapted from Mat 5001, Ref. 1.

MT=102

The low energy neutron capture in sodium is dominated by the 2.85 keV resonance. There are no data which indicate that the gamma-ray spectrum observed at thermal should not apply to the 2.85 keV resonance. We have therefore used a single gamma ray spectrum to describe capture over the complete energy range. The multiplicities were arrived at from a decay scheme based on the very consistent thermal capture data on Ref. 4 and 5.

File 14

All gamma rays have been assumed to be isotropic. There is sufficient information on many transitions to generate fairly accurate angular distributions should the need arise.

File 15

The continuous photon energy spectra for MT=91 in this file were taken from Mat 5001.

File 23

The semi-empirical photon cross section information in this file is from UCRL 50400

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I. Magnesium (MAT 1014)

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A. Outline of Cross Sections Included

Smooth total, elastic, inelastic, (n,2n), (n,γ), (n,p) and (n,α) cross sections are given in File 3, along with values of μ_L, ξ and γ calculated from the Legendre coefficients of File 4. The energy range is 0.001 eV to 18 MeV.

File 4 includes Legendre coefficients in the center of mass system for elastic scattering at 33 energies, along with the transformation matrix from the center of mass to the laboratory system.

File 5 presents secondary energy distributions for inelastic scattering to four resolved levels and the continuum, along with tabulated nuclear temperatures. Nuclear temperatures for the (n,2n) reaction are also given.

Parameters for the free gas thermal scattering law are given in File 7.

No resonance parameters are included for magnesium.

B. Sources of Magnesium Data

The main source of magnesium data was the compilation by N. Tralli et al., of United Nuclear Corporation. (Ref. 1). This compilation presents smooth cross section data and Legendre coefficients for elastic scattering angular distributions at 400 fixed energies from 0.0383 eV to 18 MeV. Various modifications were made in the UNC-5002 (Ref. 1) data, along with some additions. The data sources for the individual quantities are described in more detail below.

Total Cross Section

The total cross section over most of the energy range is from Table 13 of UNC-5002. Not all energies in Table 13 were used in the present tabulation, either for the total cross section or for other cross sections, in regions where the cross sections are slowly varying. The total cross section was extended downward to 0.001 eV as the sum of constant scattering and 1/V capture cross sections. From about 2.3 MeV to about 8.5 MeV, total cross sections based on the more recent measurements presented on the Figures on pages 12-0-3 and 12-0-4 of Ref. 2 were used.

Elastic Scattering Cross Section

The elastic scattering cross section over most of the energy range was taken from Table 13 of UNC-5002, with a constant value of 3.41 barns being used below 1.5 eV. Since new total cross sections were used from 2.3 to 8.5 MeV, new elastic cross sections were determined in this range by subtracting the other cross sections from the total.

Inelastic Scattering Cross Section

The inelastic scattering cross section is based on Table 13 of UNC-5002, with the (n,n′) and (n,np) cross sections being added to give the inelastic cross section at high energies.

(n,γ) Cross Section

The (n,γ) cross section is from Table 13 of UNC-5002, extended down to 0.001 eV on a 1/V basis with a cross section of 0.073 barns at 0.0253 eV.

(n,2n), (n,p) and (n,α) Cross Sections

Values of $\sigma_{n,2n}$, σ_{np} and $\sigma_{n\alpha}$ are all from Table 13 of UNC-5002.

μ_L, ξ and γ

The values of μ_L, ξ and γ were calculated from the Legendre coefficients of File 4. A code was written using modified versions of some of the CHAD code (Ref. 3) subroutines for this purpose. The CHAD code already had provision for calculation of μ_L and ξ. The calculation of γ is done in a manner similar to that of ξ, presented in Section VII of Ref. 3. Since there is a tendency for large terms to almost cancel one another in the calculation of γ, and to a lesser extent in the calculation of ξ, especially for heavy elements, the computations were done using double precision arithmetic on the CDC-3600, which involves approximately 25 decimal digits.

Elastic Scattering Legendre Coefficients

Legendre coefficients in the center of mass system were obtained from Table 14 of UNC-5002, with enough energies being chosen so that linear-log interpolation could reasonably be used between successive energies. Truncation of the series after too few terms at high energies in Table 14 leads to negative $\frac{d\sigma}{d\Omega}$ values over part of the angular range. Thus the coefficients at 9.89 MeV were slightly modified, and the coefficients at 14 MeV and 18 MeV were derived from Abacus-2 (Ref. 4,5) optical model calculations. The well parameters used in Abacus-2 were those of Bjorklund and Fernbach (Ref. 6), since the Legendre coefficients at high energies in Table 14 are based on their optical model calculations.

The angular distributions from the Abacus-2 problems were fit by least-squares techniques using the Argonne code, SAD (Ref. 7). The maximum number of Legendre coefficients used in the magnesium angular distributions is 10. Thus a transformation matrix from the center of mass to the laboratory system involving terms through $\ell = 10$, calculated with the CHAD code, is included in File 4.

Secondary Energy Distributions

Probabilities of exciting each of the four resolved levels considered in inelastic scattering are tabulated from threshold up to 6.0 MeV, based on Table 15 of UNC-5002. A nuclear temperature for continuum inelastic scattering is tabulated for higher energies. This was determined as follows. At several energies nuclear temperatures were found for the Maxwellian distribution which would give the same average energy loss as the tabulated values of $\sigma_{nn'}(E,E')$ in Table 16 of UNC-5002, which correspond to distributions that are decidedly non-Maxwellian. A smooth curve of temperature vs. energy was drawn, guided by these calculated temperatures. This led to nuclear temperatures of the same order of magnitude as those given by the Yiftah-Okrent-Moldauer prescription (Ref. 8) over part of the range, but which decreased drastically at high energies.

Nuclear temperatures for the (n,2n) reaction are given at the threshold and at 18 MeV, determined as follows. In Ref. 9, one neutron was assumed to have an energy $E' = 0.3(E-E_{thr})$, and another an energy $E' = 0.4(E-E_{thr})$, where E_{thr} is the threshold energy. Since the peak of a Maxwellian distribution occurs at $E' = \theta(E)$, the value of $\theta(E)$

at 18 MeV was taken as 0.35 $(E-E_{thr})$ MeV. At $E = E_{thr}$, an arbitrary value of 0.1 MeV was used rather than zero, since a zero value might cause difficulty in processing programs.

Thermal Neutron Scattering Law

A free gas thermal scattering law was assumed. The cutoff above which the static model is used was taken to be 1.5 eV, and a value of 3.41 barns was used for the free atom scattering cross section.

C. Comments on Magnesium Cross Sections

The radiative capture cross section is quite uncertain except at thermal and near thermal energies. Even at thermal energy, the value of 0.073 barns used at 0.0253 eV is somewhat higher than the value of 0.063 ± 0.005 barns recommended in Ref. 2. Since the capture cross section is rather small, the errors are probably tolerable.

The inelastic scattering cross section is uncertain at high energies, although it should be reasonably good over most of the energy range.

The procedure used in UNC-5002 to obtain the (n,2n) cross section yields only a very rough estimate, but the high threshold for this reaction makes it of little importance for reactor calculations.

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SUMMARY DOCUMENTATION FOR ALUMINUM *

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ABSTRACT

A preliminary evaluation of the neutron and photon-production cross sections of ^{27}Al is presented, covering the range 10^{-5}eV to 20 MeV. For a full description, see LA-4726. The following files are included:

File 1. Summary of the method of evaluation, with tables of the Q-values corresponding to each MT number and a list of the most important references.

File 2. Effective scattering radius of 3.468 fm, corresponding to the zero-energy scattering cross section of 1.511 b.

File 3. Smooth cross sections, including the total cross section, elastic scattering, inelastic scattering, and the (n,γ), (n,p), (n,d), (n,t), (n,α), and (n,2n) reactions. The (n,n'p) and $(n,n'\alpha)$ reactions are included in the (n,n') cross section, using flags to indicate the mode of decay. Excitation of high-lying levels is grouped into discrete bands instead of a continuum, to permit calculation of the correct energy-angle relations in the lab system.

File 4. Secondary-neutron angular distributions, given as Legendre coefficients in the C.M. system for inelastic scattering and as normalized probability distributions in the lab system for the (n,2n) reaction.

File 5. Secondary-neutron spectrum for the(n,2n) reaction in the lab system.

File 12. Photon multiplicities for the (n,γ) reaction.

File 13. Photon-production cross sections for $(n,x\gamma)$ reactions, consistent with the excitation cross sections in File 3.

File 14. Angular distributions of photons from radiative capture and $(n,x\gamma)$ reactions, assumed isotropic in all cases.

File 15. Continuous-energy spectra of photons from radiative capture, inelastic scattering, and the $(n,p\gamma)$ reaction.

NEUTRON CROSS SECTIONS

MAT #1135 contains a preliminary evaluation of the neutron and photon-production cross sections of ^{27}Al. Although it has been accepted for circulation in ENDF/B-III, extensive revisions of this evaluation are planned for the future, and it should be recognized that the literature search is incomplete, some experimental work has been ignored and much of it has not been studied critically before inclusion, the treatment of resolved resonances is sketchy, much of the partially-resolved fine structure has been smoothed out, and only a bare

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minimum of supporting nuclear-model calculations have been carried out. A more complete description of the evaluation is given in LA-4726.

The evaluated total cross section was determined entirely from experimental measurements, using the time-of-flight results of Schwartz (Sc70) and of Foster and Glasgow (Fo71) and the point-by-point results of Carlson and Barschall (Ca67) in the MeV region as a starting point. These three measurements agree within better than 2% (allowing for differences in resolution) over a wide energy range, so older work in this range was simply ignored. The high-resolution results of Cierjacks et al. (Ci68) exhibit several percent of residual dead-time errors, even after recorrection in accordance with later studies, so the actual evaluation was taken from Cierjack's results normalized to the composite of the other three recent measurements.

The Cierjacks work begins at 0.46 MeV, and was extended to lower energies by normalizing the results of Chien and Smith (Ch66) to Ci68 just above 0.46 MeV, and normalizing the work of Hibdon (Hi59) and of Merrison and Wiblin (Me52) to that. This lower-energy extension then served to normalize the results of Garg et al.(Ga65), which have the best resolution below 0.2 MeV, but which have absolute values that are unreliable by as much as 20%. The normalized results of Merrison and Wiblin (Me52) below the 6-keV resonance served to determine a zero-energy potential-scattering cross section of 1.511 barns, and the low-energy end of the free-atom total cross section was reconstructed from this scattering cross section plus the 1/v radiative capture cross section taken from Goldman's evaluation (Go71). The narrow resonances below 0.25 MeV were smoothed with approximate single-level Breit-Wigner fits and assigned the energies given by Garg's measurements (Ga65). From 0.25 to 3 MeV the fluctuating cross section was smoothed with a sliding polynomial fit. Above 3 MeV the fluctuations, although still clearly visible in the data, were deliberately smoothed out in order to reduce the number of points required to represent the total cross section. The entire energy range is represented pointwise in File 3, and no effort has been made to describe the resolved resonances in File 2.

The evaluated elastic cross section at neutron energies below 5 MeV was determined by subtracting the sum of the individual reaction cross sections from the evaluated total cross section. In the region from 5 to 16 MeV the emphasis was shifted, and the elastic and nonelastic cross sections were determined simultaneously from a composite of the available elastic measurements (Be56, Be58, Co58, Co59, Ho69, Ki70, Mi68, St59, St65) and the nonelastic measurements (Ba58, Be56, Ch67, De61, De65, Fl56, Gr55, Ma57, Ph52, Ta55), assuming the total cross section to be a known quantity. In the region from 5 to 9 MeV, the above data were augmented by nonelastic information obtained by combining the evaluated (n,p) and (n,α) cross sections with the total (n,n') cross section, as estimated from the sum of all ground-state transitions in the (n,n'γ) measurements of Di71. The resulting elastic cross section in the region from 9 to 16 MeV is systematically lower than half the total cross section. Between 16 and 20 MeV, the elastic was arbitrarily extrapolated to reach half the total cross section at 20 MeV.

The (n,n') cross sections to the first thirteen excited states of ^{27}Al (MT = 51-63, E_x < 5 MeV) are based on inelastic neutron (To62, Ts61, Wi63) and photon-production (Ch68, Ma65) measurements below E_n = 5 MeV, on the evaluation of several measurements by Dickens (Di71) for E_n = 5-9 MeV, and on a smooth extrapolation passing through the 14-MeV measurements (St65, Bo65a) for the energy region 9 to 20 MeV. To estimate the (n,n') cross section to levels with E_x > 5 MeV, the total inelastic cross section was taken as the evaluated nonelastic cross section minus the contributions from the known reaction channels, and the difference between that and the cross sections to discrete states in ^{27}Al ($E_x < 5$ MeV) was assigned to 27 groups of unresolved levels ("bands") with average excitation energies from 5.25 to 18.875 MeV. This treatment as quasi-discrete levels allows the energy-angle relationships to be preserved in the laboratory coordinate system; in particular, it preserves the forward peaking of the lower-energy secondary neutrons due to center-of-mass motion. The cross section was apportioned among the groups by an evaporation-model calculation, using temperatures inferred from measurements of secondary-neutron spectra at 7 MeV (Th63) and 14 MeV (Gr53). Those bands which correspond to excitation energies above the (n,n'p) threshold are flagged in the ENDF/B records to indicate proton emission, and at somewhat higher excitation energies, several bands are flagged as decaying by alpha emission. These (n,n'p) and (n,n'α) data are only found under MT = 64 - 90 in File 3; that is, explicit entries for MT = 22 and 28 are not present in the neutron files.

Since only a fraction of the (n,2n) cross section goes to the easily-detected 6.5-min isomer of ^{26}Al, the (n,2n) cross section from threshold to 20 MeV was estimated by assuming arbitrarily that half of the excitation cross section of levels in ^{27}Al above the (n,2n) threshold leads to neutron emission rather than proton or alpha emission, and diverting the cross section which would otherwise have been in File 3, MT = 64 - 90, into MT = 16. Except for giving the (n,xγ) cross sections for some of the intense lines, no attempt has been made to divide the (n,x) cross sections into their respective ground-state and excited-state excitations for levels in ^{26}Al. The (n,p) cross section was taken from an evaluation by Joanou and Stevens (Jo64) up to 5 MeV, and extended to 20 MeV using activation measurements (Bo59, Fe67, Ga62, Gr67, Ma60, and several additional 14-MeV experiments). The (n,d) cross section is given by a curve which has the same general shape as the (n,p) curve (but shifted in energy) and which passes through the single measurement (Gl61) at 14 MeV. The (n,t) cross section was similarly assumed to exhibit the same shape as the (n,d) cross section, with a maximum value of 15 mb at 20 MeV. The (n,α) cross section, on the other hand, has been the subject of numerous measurements (Ba61, Ga62, Gr58, Gr67, Im64, Ke59, Ma60, Pa65, Sc61, plus several 14-MeV experiments), and the evaluated curve is based upon the experimental data.

The angular distributions for elastic scattering are given in File 4 by Legendre coefficients in the C.M. system. These were obtained by passing smooth curves through the coefficients obtained from fitting all of the available data (mainly Be58, Ch66, Ki70, La57, To62, Ts61) without any attempt to evaluate the individual experiments or to reproduce the rapid changes with energy at the lower neutron energies. An optical-model calculation was used to interpolate between measurements below 15 MeV and a single measurement at 24 MeV (St62). Wherever necessary, the fits were forced to satisfy Wick's limit by adding an artificial point at 0° with a small standard deviation, and the smoothed coefficients were adjusted empirically at the end of the evaluation so as to conform to Wick's limit between the energies of the experiments. The angular distributions for inelastic scattering were assumed to be isotropic in the C.M. system, without attempting to consider the available measurements. As pointed out above,they can be substantially anisotropic in the lab system.

The angular distributions for the (n,2n) reaction in File 4 are given as normalized pointwise distributions in the lab system and were obtained by assuming isotropic emission of a dineutron in the C.M. system and transforming to the lab system via the 2-body Jacobian. These calculations were performed at each incident neutron energy using mean Q-values for the (n,2n) reaction which were obtained from the secondary-energy distributions given in File 5. The energy distributions were estimated by assuming that the (n,2n) reaction procedes sequentially as ^{27}Al (n,n')^{27}Al* (n'')^{26}Al*, with the distribution of emitted neutrons in each step being represented by a Maxwellian. Nuclear temperatures based on secondary-neutron spectrum measurements at 7 MeV (Th63) and 14 MeV (Gr53) were used in the calculations. The assumption was made that levels in ^{27}Al decay 100% by particle emission if energetically possible; this assumption is not valid for levels slightly above the separation energy and leads to a rather abrupt cutoff in the distributions at the maximum energies for emitted neutrons.

PHOTON-PRODUCTION CROSS SECTIONS

The cross section for radiative capture is given in File 3. At the lowest energies it varies as 1/v from an evaluated (Go71) 232 mb at 2200 m/sec. From 1 to 140 keV the data of Block (Bl68) were taken, but the widths of the sharp resonances were taken from the total cross section. Other measurements (Ca62, He50, He53) were used to extend the evaluation to 5 MeV. Two points near 14 MeV (Cs53, Pe58) gave evidence of a major increase in cross section in the inverse photonuclear giant resonance; for the present preliminary evaluation the curve was assumed to be a straight line from 5 to 14 MeV, with a constant cross section above 14 MeV. The thermal multiplicities in File 12 were taken mainly from the compilation of Bartholomew et al. (Ba67), but using the energies given by Rasmussen et al. (Ra70). Preliminary measurements by Jurney (Ju71) with a very pure sample showed that all of the weak lines below 1 MeV given by Rasmussen are spurious, so these were discarded. The existing measurements and their derived decay schemes do not begin to account for the very high intensity of the decays from the lowest levels in ^{28}Al. Accordingly, a continuous spectrum has been given in File 15, based on the weak lines and "continuum" of Rasmussen, which supplies the missing excitation of the low-lying levels without any further attempt at internal consistency.

The (n,n'γ) cross sections in File 13 for discrete gamma rays come directly from the excitation cross sections in File 3 via the decay scheme of ^{27}Al for neutron energies up to 5 MeV. Above 5 MeV they follow the photon-production measurements (Be66, Bo65, Ca60, Cl69, Di71, Dr70, En67, Ma68, Pe64, Pr60) supplemented by simple statistical-model calculations. These calculations were also used to estimate a photon-production cross section and secondary-energy distribution from (n,n') reactions to a continuum of levels in ^{27}Al with $E_x > 5$ MeV. The calculations, which were performed with the code SPECT10, assume that the (n,n') reaction populates states with a probability proportional to $\epsilon\rho(E)$, where ϵ is the center-of-mass energy of the outgoing neutron and ρ (E) is the density of states at excitation energy E in the residual nucleus, and that the probability for gamma ray transitions from energy E to E' in the residual nucleus is proportional to $(E-E')^3 \rho(E')$. The density-of-states function was assumed to be of the form $\rho(E) \sim \exp(E/T)$ for the calculations using temperatures based on the 7 MeV (Th63) and 14 MeV (Gr53) secondary-neutron spectrum measurements, as mentioned earlier.

The photon cross sections and energy distributions from the (n,2nγ) and (n,npγ) reactions were estimated from similar calculations, using the (n,2n) and (n,np) cross sections discussed earlier. The (n,2nγ) results are included in the continuum contributions given under MT = 4 in Files 13 - 15.

The (n,npγ) results, which are given separately as MT = 28 in Files 13 - 15, were adjusted to agree with measurements of the strong 1.809-MeV gamma ray (En67, Cl69). The entries for (n,pγ) were taken from the Dickens measurement (Di71) up to 9 MeV and were smoothly extrapolated to 20 MeV.

The angular distributions are assumed isotropic for all gamma rays in File 14.

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14-SI 1151 BNL,GGA GA-8628 (MAY 68) AUG71 M.K.DRAKE (MOD.BY R.KINSEY AUG71)

Notes on Si Evaluation

by

R. R. Kinsey

FILE 3

Section 1 - Total Cross Section

Below 5 keV the total cross section is taken as the sum of a constant scattering cross section and a 1/v radiative capture cross section.

From 5 to 100 keV, the cross section is a smooth curve through the data of Fields and Walt.(1)

From 100 to 500 keV, the cross section is based on the results of Whalen and Meadows.(2)

As of January 15, 1972, the cross section from .5 to 20 MeV has been modified only in the range from 1.8 to 3.62 MeV to represent the more recent data of Karlsruhe.(3) The file represents the data of Cox(4) for the range from .5 to 1.2 MeV, Frier, et al.(5) from 1.2 to 1.8, Karlsruhe(3) from 1.8 yo 3.62, Foster(6) from 3.62 to 5.0, Carlson and Barschall(7) from 5 to 14 MeV as adjusted as recommended by Davis and, Noda,(8) and Peterson, et al.,(9) and Day and Henkel(10) from 14 to 20.

Section 2 - Elastic Scattering Cross Section

Below 5 keV the elastic cross section is taken as 2.15 b based on the measurements of Niklaus, et al.(11) and Wiess.(12) From 5 keV to 20 MeV, it was obtained by subtracting the nonelastic from the total cross section.

Section 3 - Nonelastic Cross Section

For neutron energies below 9 MeV, the nonelastic cross section is the sum of the (n,γ), (n,n'), (n,p), and (n,α) cross sections. Above 9 MeV, the cross section was obtained from an optical model code.

Section 4 - Total Inelastic Scattering Cross Section

The total inelastic cross section was obtained by summing the cross sections for excitation of individual levels for neutron energies up to 9 MeV. Above 9 MeV, the cross section is the difference between the nonelastic and the sum of the (n,p), (n,α), (n,2n), and (n,γ) cross sections.

Section 16 - (n,2n) Cross Section

The (n,2n) cross sections for ^{29}Si and ^{30}Si have been calculated with a simple statistical model. These cross sections combined with the measured values of Arnold[13] for ^{28}Si from threshold at 17.7 MeV to 18.3 MeV have been used to estimate the (n,2n) cross section for natural silicon.

Section 28 - (n,np) Cross Section

A recommended (n,np) cross section was obtained using the value of Allan[14] to establish the magnitude of the cross section at 14 MeV and extrapolating from threshold.

Sections 51 to 91 - Inelastic Excitation Cross Sections for Discrete Levels and the Continuum

The recommended cross section for the 1.7787(2^+) MeV level which is the major part of the inelastic scattering cross section below 6 MeV was obtained in the energy range from 1.85 to 3.53 MeV from the data of Perey.[15] Between 3.53 and 7.5 MeV, the cross section has been obtained by drawing a curve through the available experimental data. Above 7.5, a smoothly decreasing curve was drawn through a value of 0.430 b as measured by Sattler, et al.[16] to a value of 0.1106 at 14.5 MeV obtained from the data of Stelson, et al.,[17] Clarke and Cross,[18], and Martin, et al.[19]

Cross section for the 4.614(4^+), 4.975(0^+), and 6.272(3^+) levels used the experimental data of Sattler, et al.[16] between 6.0 and 7.5 MeV and the data of Stelson, et al.[17] and Clarke and Cross[18] near 14 MeV with the general shape of these cross sections as calculated by the ELIESE code.[20]

The ELIESE Code was used to calculate the cross sections of seven levels between 6.878 and 8.260 MeV. All levels up to 6.887 cover the energy range from threshold to 20 MeV. For higher energies, the cross sections extend up to 9 MeV.

Cross sections for the first five levels in ^{29}Si and the first four levels in ^{30}Si up to 4 MeV were obtained by using optical model and Hauser-Feshbach calculations combined with measurements by Lind and Day.[21] Above 4 MeV it was assumed the total contribution of the minor isotopes of Si were constant with energy.

The continuum cross section from 4 to 9 MeV is a constant representing the total contribution of the minor isotopes. Above 9 MeV the continuum is the difference between the sum of the discrete levels of ^{28}Si up to the 6.887 MeV level and the total inelastic cross section.

Section 102 - Radiative Capture Cross Section

The (n,γ) cross section has been obtained up to 20 keV by using a value of 0.16 b at .0253 eV and assuming a 1/v energy dependence. From 20 keV to 200 keV, the cross section is based on an analysis by Macklin and Gibbons.[22] Between 200 keV and 20 MeV, the (n,γ) cross section is assumed to be relatively constant.

Section 103 - (n,p) Cross Section

The recommended (n,p) cross section for natural silicon was obtained by adding small contributtions from the ^{29}Si and ^{30}Si (n,p) cross sections to the evaluated (n,p) cross section of ^{28}Si. Below 6 MeV, the ^{28}Si (n,p) cross section was based on the data of Marion, et al.[23] From 6 to 9 MeV, the experimental results of Bass, et al.[24] were used. From 9.0 to 12.6 MeV, a smooth curve was drawn to join with the data of Kern, et al.[25] at 12.6 which was renormalized to a value of 220.0 mb at 14.5 MeV. From 12.6 to 20.0 MeV, the curve follows the renormalized data of Jeronymo, et al.[26] and Kern, et al.[25] The ^{29}Si and ^{30}Si contributions were estimated by using values of 101.0 mb and 180.0 mb for these isotopes at 14.0 MeV and using the same general shape for the cross section as obtained for ^{28}Si.

Section 104 - (n,d) Cross Section

A speculative (n,d) cross section has been obtained by starting with a value of zero at 10.5 MeV, passing through a maximum value of 19 mb at 14 MeV and decreasing to .7 mb at 20 MeV.

Section 107 - (n,α) Cross Section

The (n,α) cross section of ^{28}Si below 6.2 MeV was obtained using the data of Bety and Rössle.[27] Between 6.2 and 8.4 MeV, the values measured by Mainsbridge, et al.[28] reduced by 30% were used. From 8.4 MeV, the recommended cross section increases to a peak value of 3/8.6 mb at 11 MeV and then decreases to a value of 275.0 mb at 14.0 MeV. Above 14 MeV, the curve was extrapolated to 20 MeV using the observed shape of the partial (n,α) cross sections.

The ^{29}Si (n,α) cross section was obtained from the data of Konijn and Lauber[29] for neutron energies between 2.4 and 3.5 MeV. Between 3.5 and 5.5 MeV, the data of Potenza, et al.,[30] Birk, et al.,[31] and Mainsbridge, et al. were used. From 5.5 to 8.0 MeV, the data of Bety and Rössle[27] were used. Between 8 and 20 MeV, a curve reaching a maximum of 123 mb as measured by Khurana and Govil[32] at 11 MeV was drawn.

The ^{30}Si (n,α) cross section was obtained using the general energy shape of ^{28}Si, starting from threshold and passing through a value at 14 MeV based on the ratio of the cross sections for the silicon isotope calculated by Gardner and Yu.[33]

The (n,α) cross section for natural silicon was then obtained by combining the isotopic cross sections using the fractional abundance.

Sections 251, 252, and 253

The slowing down parameters for elastic scattering were calculated using the angular distributions of elastically scattered neutrons in Section 2, File 4.

FILE 4

Section 2 - Elastically Scattered Neutrons

Below 158 keV, the angular distributions are given as isotopic as boserved by Lane, et al.[34] Between .15 and 0.7 MeV, the distributions of Lane, et al.[35] have been used. For 0.7 to 1.17 MeV, the data of Cox[36] was used. For neutron energies from 1.2 to 3.0 MeV, the recommended data were measured by Lane, et al,[34] Bredin,[37] Coppola and Knitter,[38] and Olkhovaskii and Tsekhmstrenko.[39] The experimental results of Popov,[40] Tsukada, et al.,[41] and Sattler, et al.[16] were used in the energy range from 3.0 to 7.0 MeV. From 7.0 to 20.0 MeV the recommended distributions were obtained using the ELIESE code[20] which was in good agreement with the available experiments.

Section 16 - (n,2n) Angular Distributions

The (n,2n) angular distributions were assumed to be isotropic.

Section 28 - (n,np) Angular Distributions

The (n,np) angular distributions were assumed to be isotropic.

Section 51 to 91 - Inelastically Scattered Neutrons

For the 1.78 MeV(2^+) level in ^{28}Si the angular distributions from threshold to 3.5 MeV were taken from calculated results of the ELIESE Code.[20] In the energy range from 3.5 to 7.5 MeV, the data of Pititt, et al.[16] were used. At 14 MeV, the experimental results of Clarke and Cross[18] were used.

For the 4.61 MeV(4^+) and 4.98(0^+) levels of ^{28}Si, the calculated distributions were used from threshold to 6.0 MeV. Between 6.0 and 7.5 MeV, the distributions of Sattler, et al.[16] were used. Above 7.5 MeV, calculated distributions have been used.

For the 6.27, 6.88, 6.89, and 7.38 MeV levels, the calculated angular distributions were used. All other levels were assumed to have isotropic distributions in the center-of-mass system.

FILE 5

Energy Distribution of Secondary Neutrons

Sections 16 and 28 - (n,2n) and (n,np) Reactions

The energy distributions of neutrons from (n,2n) and (n,np) reactions were considered to have a Maxwellian shape. The same nuclear temperature was assumed as was used for the (n,n') reaction. This temperature was assumed to be proportional to the square root of the energy.

Section 91 - Inelastically Scattered Neutron Continuum

An evaporation-type spectrum has been used to describe the secondary energy distributions. The nuclear temperature obtained by Anufrienko, et al.[43] has been used at 14.1 MeV. For other neutron energies, the nuclear temperature was assumed to be proportional to the square root of the energy.

FILE 12

Section 102 - Radiative Capture Gamma Rays

The recommended multiplicaties for the radiative capture gamma rays of .00001 eV to 50 keV neutrons were obtained from the thermal neutron capture experiments of Spits, et al.,(44) Lycklama, et al.,(45) and Blichert-Toft and Tripathi.(46)

From 50 keV to 20 MeV, the gamma spectra of Lundberg and Bergqvist(47) measured at 68 keV was used. For incident neutron energies from 50 keV to 1 MeV the spectra are represented as discrete gamma rays in 1 keV steps. From 1 MeV to 20 MeV, a continuum representation is used.

FILE 13

Section 3

This section was used to represent that part of the gamma ray production cross section from 9 to 20 MeV that was treated as a continuous spectrum. It was obtained by subtracting the sum of the production cross section for discrete gamma rays from the total production cross section.

Section 4 - (n,n'γ) Production Cross Sections

The cross sections of discrete gamma rays were obtained up to 9 MeV using the excitation cross sections of File 3, Sections 51-71, and the transition probabilities given in Section 2.4 of the primary documentation.

Using the data of Engesser and Thompson,(48) Caldwell, et al.,(49) Nellis, et al.,(50) and Martin and Stewart,(51) the gamma ray production cross section of the 1.78, 6.878, 5.108, and 2.835 MeV gamma rays were determined at 14.5 MeV. For these gamma rays, the production cross sections were obtained by extrapolating the values at 9 MeV to 20 MeV and passing through the 14.5 MeV values.

Section 103 - (n,pγ) Gamma Rays

The production of photons from the (n,pγ) reactions were obtained up to 9 MeV by analyzing the partial (n,p) cross sections in this energy range and using transition probabilities. The experimental measurements used were Andersson-Lindstrom and Rössle,[52] Mausberg,[53] and Debertin, et al.[54]

Section 107 - (n,$\alpha\gamma$) Gamma Rays

The gamma ray production cross sections up to 9 MeV were obtained by using the partail cross sections and transition probabilities. The (n,α_0) cross section was measured by Bety and Rössle[27] and Miller and Kavanagh.[55] The (n,α), (n,α_2), and (n,α_3) cross sections were obtained by reducing the values of Mainsbridge, et al.[28] by 30%. The (n,α_4) cross section was deduced from values by Shannon and Trice.[56] For the .9747, .5852, and .3894 MeV gamma rays, values obtained at 14.7 MeV by Engesser and Thompson[48] were used to extrapolate from 9 to 20 MeV.

FILE 14

Sections 3, 102, 103, and 107

The photons that were treated as a part of the continuum and the photons from (n,γ), (n,pγ), and (n,$\alpha\gamma$) reactions were assumed to be isotropic.

Section 4

The angular distributions of secondary gamma rays from the (n,n'γ) reaction were calculated using the MANDY Code.[56]

FILE 15

Section 3

The recommended secondary gamma ray energy distributions for that part of the gamma ray production cross section between 9 and 20 MeV treated as a continuous spectra of photons in Section 3, File 13, has been obtained using a Maxwellian type spectra. The empirically determined temperatures of Howerton and Plechaty[58] have been used.

Section 102

The recommended gamma ray energy distributions for that part of the radiative capture of neutrons from 1 to 20 MeV represented as a continuum in Section 102, File 12, has represented in this section as normalized probability distributions.

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17-CL 1149 GGA GA-7829 VOL 4 (67) FEB67 M.S.ALLEN,M.K.DRAKE

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                  ENDF/B MATERIAL NO= 1149
CHLORINE  GGA          EVAL=FEB67 M,S,ALLEN AND M,K,DRAKE
GA-7829 VOL=4(1967)  DIST=JAN72 REV-JAN72
*        *          *         *         *         *         *
NATURAL CHLORINE
  THE EVALUATION IS DESCRIBED IN GA-7829 VOL=IV (FEB,1967)
  (NDL-TR-89, PART IV)
*        *          *         *         *         *         *
THE LOW ENERGY RADIATIVE CAPTURE (MT=102) AND (N,P) (MT=103)
CROSS SECTIONS WERE MODIFIED JAN,1972 TO CONFORM TO THE
RECOMMENDED 2200 M/SEC VALUES (CSEWG NORMALIZATION AND STANDARDS
SUBCOMMITTEE) THE 2200 M/SEC VALUES WERE
                          N,GAMMA   = 32,85 BARNS
                          N,PROTON  =  0,355 BARNS
*        *          *         *         *         *         *
FILE 3
          TOTAL CROSS SECTION
UP TO 4 KEV THE DATA OF BRUGGER, ET AL(1) WERE USED
FROM 4 TO 50 KEV THE DATA OF GARG ET AL (2) WERE USED
FROM 50 TO 200 KEV THE DATA OF NEWSON, ET AL (3) WERE USED
FROM 200 TO 1000 KEV THE DATA OF KIEHN, ET AL (4) WERE USED
ABOVE 1,0 MEV THE RECOMMENDED CURVE WAS BASICALLY BASED ON THE
MEASUREMENT OF GLASGOW AND FOSTER (5)
                                                                *
          N,GAMMA CROSS SECTION
THE X/S WAS TAKEN TO BE 1/V NEAR THERMAL NEUTRON ENERGIES
ABOVE 20 EV THE DATA OF KASHUKEEV (6) AND MACKLIN (7) WERE USED
          INELASTIC CROSS SECTIONS
UP TO 7,0 MEV THE TOTAL AND DISCRETE LEVEL  EXCITATION CROSS
SECTIONS WERE OBTAINED USING THE ABACUS-II CODE
ABOVE 7,0 MEV THE TOTAL INELASTIC CROSS SECTION WAS OBTAINED
BY SUBTRACTING OTHER PARTIAL X/S FROM THE NON-ELASTING CROSS
SECTION WHICH WAS BASED ON DATA MEASURED BY PASECHNIK (8)  AND
FRASCA (9)
                                                                *
          N,P CROSS SECTION
UP TO 10 EV THE X/S WAS TAKEN TO BE 1/V
FROM 10 EV TO 10 KEV THE DATA SHOWN IN BNL-325 (1964) WERE USED
FROM 3,0 MEV TO 20 MEV A SMOOTH CURVE WAS DRAWN THROUGH THE
EXPERIMENTAL DATA MEASURED BY MATHUR AN MORGAN (10), COHEN AND
WHITE (11), AND PAUL AND CLARKE (12)
                                                                *
          N,2N CROSS SECTION
THE N,2N CROSS SECTION WAS BASED ON EXPERIMENTAL MEASUREMENTS
OF EACH ISOTOPE
*        *          *         *         *         *         *
FILE 4
          ELASTIC SCATTERING
THE RESULTS FROM OPTICAL MODEL CALCULATIONS WERE USED (SEE REPORT
       OTHER REACTION
ANGULAR DISTRIBUTIONS OF NEUTRONS FROM DISCRETE LEVEL INELASTIC
SCATTERING WERE OBTAINED USING THE ABACUS CODE,
OTHER NEUTRONS WERE ASSUMED TO BE ISOTROPIC,
*        *          *         *         *         *         *
FILE 5
A STATISTICAL MODEL WAS USED TO DESCRIBE ALL SECONDARY NEUTRONS
EXCEPT DISCRETE LEVEL INELASTIC
*        *          *         *         *         *         *
FILE 12
          RADIATIVE CAPTURE
THESE GAMMA RAYS WERE OBTAINED BY ANALYZING MEASUREMENTS OF
```

ENDF/B MATERIAL NO= 1149
THERMAL NEUTRON CAPTURE, THE RECOMMENDED TRANSITION PROBABILITIES WERE TAKEN FROM ENDT AND VAN DER LEUN (13) AND HAZEWINDUS (14), SINCE NO EPITHERMAL DATA WERE AVAILABLE THE SAME SECONDARY GAMMA SPECTRA WAS USED FOR ALL INCIDENT NEUTRON ENERGIES

DISCRETE INELASTIC

THE RECOMMENDED DATA WERE OBTAINED BY USING THE LEVEL EXCITATION CROSS SECTIONS AND THE RECOMMENDED BRANCHING RATIOS(SEE GA-7829)

* * * * * * *

FILE 14

ANGULAR DISTRIBUTION OF GAMMA RAYS FROM DISCRETE LEVEL INELASTIC WERE CALCULATED USING THE MANDY CODE.ALL OTHER GAMMA RAYS WERE ASSUMED TO BE ISOTROPIC

* * * * * * *

* * * * * * *

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CHLORINE**TRANSLATED AT U.VA. FROM GA EVALUATION BY DRAKE, ET AL. PLEASE REFER COMMENTS OR QUESTIONS REGARDING ERRORS IN TRANSL-TION OR IN FORMAT, OR CONCERNING THE TRANSLATION CODE (LATEX) TO

DONALD J. DUDZIAK, UNIVERSITY OF CALIFORNIA, LOS ALAMOS SCIENTIFIC LABORATORY LOS ALAMOS NM 87544

ANY COMMENTS REGARDING THE DATA EVALUATION SHOULD BE REFERRED TO M.K. DRAKE, ET AL, THE AUTHORS OF GA-7829 (NDL-TR-89). THE PER-MISSION OF MR. DRAKE TO TRANSLATE HIS EVALUATION IS GRATEFULLY ACKNOWLEDGED. TRANSITION PROBABILITY ARRAYS FOR INELASTIC SCAT-TERING WERE TAKEN FROM DIAGRAMS IN GA-7829,PART IV. DATA FOR RTN 1032 AND 3032 WERE ASSIGNED MT=28, AS RECOMMENDED BY DRAKE. TRANSLATION COMPLETED JULY, 1969.

PHOTON PRODUCTION FILES CONVERTED TO NEW FORMAT IN LA-4549(ENDF-102,REVISED,VOL. II) BY DONALD J. DUDZIAK OCTOBER 1970.

NEUTRON AND PHOTON PRODUCTION FILES CONVERTED TO ENDF/B-II FORMAT FOR THE RADIATION SHIELDING INFORMATION CENTER BY SINGLETARY, PENNY, AND ROUSSIN. FILE 2 AND FILE 23 ALSO ADDED IN MARCH 1971.

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                ENDF/B MATERIAL NO= 1149
           MT= 22   (N,N-PRIME)ALPHA       * Q=  -6.99 MEV
           MT= 28   (N,N-PRIME)P           * Q=  -6.37 MEV
           MT= 51   (N,N-PRIME) TO THE 1ST EXCITED STATE*1.220 MEV
           MT= 52   (N,N-PRIME) TO THE 2ND EXCITED STATE*1.762 MEV
           MT= 53   (N,N-PRIME) TO THE 3RD EXCITED STATE*2.645 MEV
           MT= 54   (N,N-PRIME) TO THE 4TH EXCITED STATE*2.695 MEV
           MT= 55   (N,N-PRIME) TO THE 5TH EXCITED STATE*3.006 MEV
           MT= 56   (N,N-PRIME) TO THE 6TH EXCITED STATE*3.163 MEV
           MT= 57   (N,N-PRIME) TO THE 7TH EXCITED STATE*4.058 MEV
           MT= 58   (N,N-PRIME) TO THE 8TH EXCITED STATE*4.113 MEV
           MT= 59   (N,N-PRIME) TO THE 9TH EXCITED STATE*4.174 MEV
           MT= 60   (N,N-PRIME) TO THE 10TH EXCITED STATE*5.13 MEV
           MT= 61   (N,N-PRIME) TO THE 11TH EXCITED STATE*5.22 MEV
           MT= 62   (N,N-PRIME) TO THE 12TH EXCITED STATE*6.04 MEV
           MT= 63   (N,N-PRIME) TO THE 13TH EXCITED STATE*6.10 MEV
           MT= 91   (N,N-PRIME) TO THE CONTINUUM
           MT=102   (N,GAMMA)
           MT=103   (N,P)          * Q= 0.0 MEV
           MT=107   (N,ALPHA)      * Q= 0.0 MEV
           MT=251   MU-BAR (L SYSTEM) * SAME ENERGY RANGE AS MT=1*

** MF=4 **  SECONDARY ANGULAR DISTRIBUTIONS * TABULAR * C SYSTEM
                                *NO TRANSFORMATION MATRICES *
           MT=  2   ELASTIC
           MT= 51   (N,N-PRIME) TO THE 1ST EXCITED STATE
           MT= 52   (N,N-PRIME) TO THE 2ND EXCITED STATE
           MT= 53   (N,N-PRIME) TO THE 3RD EXCITED STATE
           MT= 54   (N,N-PRIME) TO THE 4TH EXCITED STATE
           MT= 55   (N,N-PRIME) TO THE 5TH EXCITED STATE
           MT= 56   (N,N-PRIME) TO THE 6TH EXCITED STATE
           MT= 57   (N,N-PRIME) TO THE 7TH EXCITED STATE
           MT= 58   (N,N-PRIME) TO THE 8TH EXCITED STATE
           MT= 59   (N,N-PRIME) TO THE 9TH EXCITED STATE
           MT= 60   (N,N-PRIME) TO THE 10TH EXCITED STATE
           MT= 61   (N,N-PRIME) TO THE 11TH EXCITED STATE
           MT= 62   (N,N-PRIME) TO THE 12TH EXCITED STATE
           MT= 63   (N,N-PRIME) TO THE 13TH EXCITED STATE

** MF=5 **  SECONDARY ENERGY DISTRIBUTIONS
           MT= 16   (N,2N)
           MT= 22   (N,N-PRIME)ALPHA
           MT= 28   (N,N-PRIME)P
           MT= 91   (N,N-PRIME) TO THE CONTINUUM

** MF=12 **  MULTIPLICITIES OR TRANSITION PROBABILITIES
           MT= 51   (N,N-PRIME) TO THE 1ST EXCITED STATE * OPTION2
           MT= 52   (N,N-PRIME) TO THE 2ND EXCITED STATE * OPTION2
           MT= 53   (N,N-PRIME) TO THE 3RD EXCITED STATE * OPTION2
           MT= 54   (N,N-PRIME) TO THE 4TH EXCITED STATE * OPTION2
           MT= 55   (N,N-PRIME) TO THE 5TH EXCITED STATE * OPTION2
           MT= 56   (N,N-PRIME) TO THE 6TH EXCITED STATE * OPTION2
           MT= 57   (N,N-PRIME) TO THE 7TH EXCITED STATE * OPTION2
           MT= 58   (N,N-PRIME) TO THE 8TH EXCITED STATE * OPTION2
           MT= 59   (N,N-PRIME) TO THE 9TH EXCITED STATE * OPTION2
           MT= 60   (N,N-PRIME) TO THE 10TH EXCITED STATE* OPTION2
           MT= 61   (N,N-PRIME) TO THE 11TH EXCITED STATE* OPTION2
           MT= 91   (N,N-PRIME) TO THE CONTINUUM * OPTION 1
           MT=102   (N,GAMMA) * OPTION 1
** MF=13 **  PHOTON PRODUCTION CROSS SECTIONS
           MT=  3 PHOTONS FROM DE-EXCITATION OF 3 CL-37 LEVELS
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                  ENDF/B MATERIAL NO= 1149
          MT= 51 PHOTONS FROM DE-EXCITATION OF  1ST STATE
          MT= 52 PHOTONS FROM DE-EXCITATION OF  2ND STATE
          MT= 53 PHOTONS FROM DE-EXCITATION OF  3RD STATE
          MT= 54 PHOTONS FROM DE-EXCITATION OF  4TH STATE
          MT= 55 PHOTONS FROM DE-EXCITATION OF  5TH STATE
          MT= 56 PHOTONS FROM DE-EXCITATION OF  6TH STATE
          MT= 57 PHOTONS FROM DE-EXCITATION OF  7TH STATE
          MT= 58 PHOTONS FROM DE-EXCITATION OF  8TH STATE
          MT= 59 PHOTONS FROM DE-EXCITATION OF  9TH STATE
          MT= 60 PHOTONS FROM DE-EXCITATION OF 10TH STATE
          MT= 61 PHOTONS FROM DE-EXCITATION OF 11TH STATE
** MF=14 **  PHOTON ANGULAR DISTRIBUTIONS * TABULAR
          MT=  3  PHOTON PRODUCTION (3 LEVELS OF CL-37) (ISO,)
          MT= 51  (N,N-PRIME) TO THE 1ST EXCITED STATE (ISO,)
          MT= 52  (N,N-PRIME) TO THE 2ND EXCITED STATE
          MT= 53  (N,N-PRIME) TO THE 3RD EXCITED STATE
          MT= 54  (N,N-PRIME) TO THE 4TH EXCITED STATE
          MT= 55  (N,N-PRIME) TO THE 5TH EXCITED STATE
          MT= 56  (N,N-PRIME) TO THE 6TH EXCITED STATE
          MT= 57  (N,N-PRIME) TO THE 7TH EXCITED STATE
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19-K 1150 GGA GA-7829 VOL 5 (67) FEB67 M.K.DRAKE

ENDF/B MATERIAL NO= 1150
POTASSIUM GGA EVAL=1967 M.K.DRAKE
GA-7829 VOL=5 (1967) DIST=JAN72 REV-JAN72
* * * * * * *
NATURAL POTASSIUM
* * * * * * *
FILE 3
TOTAL CROSS SECTION
UP TO 10 EV A SMOOTH CURVE WAS DRAWN THROUGH THE DATA OF JOKI(1)
FROM 10 EV TO 17 KEV THE TOTAL CROSS SECTION WAS OBTAINED FROM
A RESOLVED RESONANCE CALCULATION BASED ON THE TWO PRINCIPLE
ISOTOPES. PARAMETERS OF GOOD,ET AL (2) WERE USED
BETWEEN 17 KEV AND 315 KEV A SMOOTH CURVE WAS DRAWN THROUGH THE
1958 DATA MEASURED BY NEWSON (3).
THE TOTAL CROSS SECTION WAS VERY POORLY MEASURED BETWEEN 0.3
AND 1.0 MEV. THE RECOMMENDED CURVE WAS DRAWN THROUGH DATA
MEASURED BY PETERSON (4).
BETWEEN 0.9 AND 2.10 MEV AN AVERAGED WAS TAKEN OF DATA MEASURED
BY VAUGHN (5). STRUCTURE IN THE CROSS SECTION IS PRESENT BUT
COULD NOT BE ANALYZED FROM VAUGHNS DATA.
ABOVE 2.1 MEV DATA MEASURED BY FOSTER (6) AND DECONNINCK (7)
WERE USED.
RADIATIVE CAPTURE CROSS SECTION
THE LOW ENERGY CROSS SECTION WAS MODIFIED TO AGREE WITH THE
CSEWG NORMALIZATION AND STANDARDS SUBCOMMITTEE RECOMMENDED
2200 M/SEC VALUE OF *(2.10 BARNS)*
FROM 1.0-5 EV TO 20 KEV THE CROSS SECTION WAS OBTAINED FROM THE
RESOLVED RESONANCE PARAMETERS (SEE GA-7829 VOL-4) PLUS ADDITIONAL
1/V COMPONENT TO OBTAIN THE DESIRED 0.0253 EV VALUE
ABOVE 20KEV THE CROSS SECTION WAS DRAWN THROUGH THE EXPERIMENTAL
POINTS AT 30.5 AND 65.0 KEV MEASURED BY MACKLIN ET AL (8). THE
SLOPE WAS TAKEN TO BE THE SAME AS WAS MEASURED FOR K-41
ACTIVATION BY STUPEGIA (9).
INELASTIC SCATTERING
THE FIRST THREE LEVEL EXCITATION CROSS SECTIONS WERE BASED ON
MEASUREMENTS BY LIND AND DAY (10) AND TOWLE AND GILBOY (11) FOR
NEUTRON ENERGIES UP TO 4.0 MEV. OTHER LEVEL EXCITATION CROSS
SECTIONS WERE OBTAINED USING THE ABACUS-II CODE (SEE REPORT)
CALCULATIONS WERE MADE FOR NEUTRON ENERGIES UP TO 6.8 MEV
ABOVE 6.8 MEV THE TOTAL INELASTIC CROSS SECTION WAS TAKEN AS THE
DIFFERENCE BETWEEN THE NON-ELASTIC CROSS SECTION AND THE SUM OF
(N,P) + (N,NP) + (N,A) + (N,NA) + (N,2N). SEE REPORT FOR THE
NON-ELASTIC CROSS SECTION.
N,PROTON CROSS SECTIONS
UP TO 700 KEV THE (N,P) CROSS SECTION IS 1/V WITH A 2200 M/SEC
VALUE OF 0.051 BARNS (NORMALIZATION AND STANDARDS SUBCOMMITTEE
RECOMMENDATION).FROM 720 KEV TO 4.0 MEV MEASURED VALUES FOR THE
(N,P0) + (N,P1) + (N,P2) CROSS SECTIONS WERE USED, BASED ON
MEASUREMENTS BY BASS ET AL (12,13).
BETWEEN 4.0 AND 8.0 MEV THE DATA OF BASS ET AL (13) WERE USED
THE RECOMMEND CURVE WAS EXTRAPOLATED THROUGH TO DATA MEASURED
BY LANGKAU (14) (12.6 TO 19.4 MEV)
THE (N.NP) CROSS SECTION WAS BASED ON MEASUREMENTS MADE BY
LANGKAU (14) AND BORMANN (15).
N,ALPHA CROSS SECTIONS
UP TO 1.0 MEV THE CROSS SECTION WAS TAKEN TO BE 1/V WITH A
2200 M/SEC VALUE OF 0.2046 BARNS (NORMALIZATION AND STANDARDS
SUBCOMMITTEE RECOMMENDATION). FROM 1.0 MEV TO 3.5 MEV THE (N,A)
CROSS SECTION WAS BASED ON (N,ALPH-ZERO) MEASUREMENTS OF
BASS (12,13). FROM 3.5 TO 8.0 MEV DATA OF BASS (14) WERE USED.
ABOVE 8.0 MEV THE DATA OF BORMANN (15,16) WERE USED.

ENDF/B MATERIAL NO= 1150
THE (N,AN) CROSS SECTION WAS BASED ON DATA MEASURED BY BORMANN(15
N,2N CROSS SECTION
THE N,2N CROSS SECTION WAS BASED ON MEASUREMENTS MADE BY
BORMANN (17,18) FOR THE K-39(N,2N) K-38G REACTION AND BY
ARNOLD (19) AND BORMANN (17) FOR THE K-39 (N,2N) K-38M REACTION
* * * * * * *
FILE 4 (ANGULAR DISTRIBUTIONS)
ELASTIC SCATTERING
FROM 0.03 TO 1.3 MEV THE DATA OF LANGSDORF, ET AL (20) WERE USED
FROM 1.5 TO 3.8 MEV THE DATA OF TOWLE AND GILBOY (11) WERE USED
ABOVE 4.0 MEV THE ABACUS-II CODE WAS USED
NON-ELASTIC REACTIONS
ANGULAR DISTRIBUTIONS FOR (N,2N), (N,NP), (N,NA), AN (N,INELASTIC
CONTINUUM) NEUTRONS HAVE BEEN ASSUMED TO BE ISOTROPIC.
ANG DISTR. FOR NEUTRONS FROM DISCRETE LEVEL EXCITATION REACTIONS
HAVE BEEN CALCULATED USING THE ABACUS-II CODE.
* * * * * * *
FILE 5 (ENERGY DISTRIBUTIONS)
AN EVAPORATION MODEL HAS BEEN USED FOR MT=16,22,28, AND 91
THE EFFECTIVE NUCLEAR TEMPERATURE WAS BASED ON
T(E) = B*SQRT(E/A)
E= INCIDENT NEUTRON ENERGY
A= NUCLEAR MASS
B= 2.5 FOR MT=91, = 1.59 FOR MT= 16, 22, AND 28
(SEE VOL-1 OF GA-7829)
* * * * * * *
FILE 12 AND 13 PHOTON PRODUCTION CROSS SECTIONS
GAMMA RAYS FROM THERMAL NEUTRON CAPTURE WERE OBTAINED FROM DATA
SUMMARIZED BY ENDT AND VAN DER LEUN (21) AND GROSHEV ET AL (22)
AND MEASUREMENTS OF RUDOLPH AND GERSCH (23).
SINCE NO EPI-THERMAL MEASUREMENTS WERE AVAILABLE THE SAME SPECTRA
WAS ASSUMED FOR ALL INCIDENT NEUTRON ENERGIES.

PHOTONS FROM DISCRETE INELASTIC LEVEL EXCITATION WERE OBTAINED
FROM THE LEVEL CROSS SECTION. ALL SIX LEVELS WERE ASSUMED TO
DECAY TO THE GROUND STATE.
PHOTONS FROM (N,P1), (N,P2) AND (N,A1) REACTIONS WERE OBTAINED
BY ANALYZING THE INDIVIDUAL REACTIONS.
*
PHOTONS FROM NEUTRON REACTION ABOVE 7.0 MEV WAS BASED ON
A MEASUREMENT BY CALDWELL FOR PHOSPHOROUS. THESE DATA ARE
POORLY KNOWN.
*
THE ANGULAR DISTRIBUTIONS FOR DISCRETE PHOTONS WAS CALCULATED
USING THE MANDY CODE.
THE ANGULAR DISTRIBUTIONS FOR CONTINUUM PHOTONS WAS ASSUMED
TO BE ISOTROPIC.
* * * * * * *
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(1) E.G.JOKI, ET.AL., PHYS.REV.99,610 (1955)
(2) W.M.GOOD, ET.AL., PHYS.REV.109,926 (1958)
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(5) F.J.VAUGHN, ET.AL., NUCL.SCI.ENG. 17, 325 (1963)
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(7) G.DECONNINCK, ET.AL., J.PHYS.(PARIS) 22, 652 (1961)
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(9) D.C.STUPEGIA, ET.AL., IAEA CONF.ON NUCLEAR DATA (OCT.1966)
(10) D.A.LIND AND R.B.DAY, ANN.PHYS. 12, 485 (1961)
(11) J.H.TOWLE AND W.B. GILBOY, NUCL.PHYS. 72, 515 (1965)

ENDF/B MATERIAL NO= 1150

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(13) R,BASS, ET,AL,, ENDC(E)-57, 1965
(14) R,LANGKAU, Z,NATURFORSH, 18A, 914 (1963)
(15) M,BORMANN, ET,AL,, Z,NATURFORSH, 15A, 200 (1960)
(16) M,BORMANN, ET,AL,, Z,PHYS,166, 477 (1962)
(17) M,BORMANN, NUCL,PHYS, 65, 257(1965)
(18) M,BORMANN, ET,AL,,NUCL.PHYS, 63, 438 (1965)
(19) D,M,ARNOLD, THESIS, U, OF GEORGIA (1965)
(20) A,LANGSDORF, ET,AL,,PHYS,REF,107,1077 (1957)
(21) P,M,ENDT AND C,VAN DER LEUN, NUCL,PHYS, 34, 1 (1962)
(22) L,V,GROSHEV, ET,AL,,ATLAS OF GAMMA-RAY SPECTRA FROM RADIATIVE CAPTURE (TRANS),PERGAMMON PRESS, 1959
(23) W,RUDOLPH AND H,V,GERSCH, NUCL,PHYS, 71, 221 (1965)
(24) R,L,CALDWELL, ET,AL,, NUCL,SCI,ENG, 8, 173 (1960)

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POTASSIUM--TRANSLATED JUN 69 FROM GA EVALUATION (GA-7829, 1967) PLEASE REFER COMMENTS OR QUESTIONS REGARDING ERRORS IN TRANSLA- TION OR IN FORMAT, OR CONCERNING THE TRANSLATION CODE (LATEX)
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PHOTON PRODUCTION FILES CONVERTED TO NEW FORMAT IN LA-4549(ENDF- 102,REVISED,VOL, II) BY DONALD J, DUDZIAK JULY 1970,
NEUTRON AND PHOTON PRODUCTION FILES CONVERTED TO ENDF/B-II FORMAT FOR THE RADIATION SHIELDING INFORMATION CENTER BY SINGLETARY, PENNY, AND ROUSSIN, FILE 2 AND FILE 23 ALSO ADDED IN MARCH 1971,

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                    ENDF/B MATERIAL NO= 1150
         MT= 65   (N,N-PRIME) TO THE 15TH EXCITED STATE*6.21 MEV
         MT= 66   (N,N-PRIME) TO THE 16TH EXCITED STATE*6.35 MEV
         MT= 67   (N,N-PRIME) TO THE 17TH EXCITED STATE*6.50 MEV
         MT= 91   (N,N-PRIME) TO THE CONTINIUUM
         MT=102   (N,GAMMA)
         MT=103   (N,P)         *  Q= 0.0 MEV
         MT=107   (N,ALPHA)     *  Q= 0.0 MEV
         MT=251   MU-BAR (L SYSTEM) * SAME ENERGY RANGE AS MT=1*

 ** MF=4 **  SECONDARY ANGULAR DISTRIBUTIONS * TABULAR * C SYSTEM
         MT=  2   ELASTIC
         MT= 51   (N,N-PRIME) TO THE 1ST EXCITED STATE
         MT= 52   (N,N-PRIME) TO THE 2ND EXCITED STATE
         MT= 53   (N,N-PRIME) TO THE 3RD EXCITED STATE
         MT= 54   (N,N-PRIME) TO THE 4TH EXCITED STATE
         MT= 55   (N,N-PRIME) TO THE 5TH EXCITED STATE
         MT= 56   (N,N-PRIME) TO THE 6TH EXCITED STATE
         MT= 57   (N,N-PRIME) TO THE 7TH EXCITED STATE
         MT= 58   (N,N-PRIME) TO THE 8TH EXCITED STATE
         MT= 59   (N,N-PRIME) TO THE 9TH EXCITED STATE (ISO.)
         MT= 60   (N,N-PRIME) TO THE 10TH EXCITED STATE (ISO.)

 ** MF=5 **  SECONDARY ENERGY DISTRIBUTIONS * ALL LAW 1 (TABULAR)
         MT= 22   (N,N-PRIME)ALPHA
         MT= 28   (N,N-PRIME)P
         MT= 91   (N,N-PRIME) TO THE CONTINUUM

 ** MF=12 **  MULTIPLICITIES OR TRANSITION PROBABILITIES
         MT= 51   (N,N-PRIME) TO THE 1ST EXCITED STATE* OPTION2
         MT= 52   (N,N-PRIME) TO THE 2ND EXCITED STATE* OPTION2
         MT= 53   (N,N-PRIME) TO THE 3RD EXCITED STATE* OPTION2
         MT= 54   (N,N-PRIME) TO THE 4TH EXCITED STATE* OPTION2
         MT= 91   (N,N-PRIME) TO THE CONTINUUM * OPTION 1
         MT=102   (N,GAMMA) * OPTION 1
         MT=103   (N,N-PRIME)P *OPTION 1*
         MT=107   (N,N-PRIME)ALPHA *OPTION 1*
 ** MF=13 **  PHOTON PRODUCTION CROSS SECTIONS
         MT= 51 PHOTONS FROM DE-EXCITATION OF  1ST STATE
         MT= 52 PHOTONS FROM DE-EXCITATION OF  2ND STATE
         MT= 53 PHOTONS FROM DE-EXCITATION OF  3RD STATE
         MT= 54 PHOTONS FROM DE-EXCITATION OF  4TH STATE
         MT= 55 PHOTONS FROM DE-EXCITATION OF  5TH STATE
         MT= 56 PHOTONS FROM DE-EXCITATION OF  6TH STATE
 ** MF=14 ** PHOTON ANGULAR DISTRIBUTIONS * TABULAR
         MT= 51   (N,N-PRIME) TO THE 1ST EXCITED STATE (ISO.)
         MT= 52   (N,N-PRIME) TO THE 2ND EXCITED STATE
         MT= 53   (N,N-PRIME) TO THE 3RD EXCITED STATE
         MT= 54   (N,N-PRIME) TO THE 4TH EXCITED STATE
         MT= 55   (N,N-PRIME) TO THE 5TH EXCITED STATE
         MT= 56   (N,N-PRIME) TO THE 6TH EXCITED STATE
         MT=103   (N,P-GAMMA)                              (ISO.)
*        *         *         *         *         *         *
*        *         *         *         *         *         *
```

20-CA 1152 ORNL,GGA GA-7829 VOL 6 (67) OCT71 F.PEREY(ORNL) M.K.DRAKE(GGA)

ENDF/B MATERIAL NO= 1152
CALCIUM ORNL EVAL=1967 F.PEREY(ORNL) M,K,DRAKE
GA-7829 VOL=6 (1967) DIST-JAN72 REV-OCT71
* * * * * * *
DATA MODIFIED JAN,72
LOW ENERGY N,ALPHA CROSS SECTION ADDED (1/V)
2200 M/SEC VALUE WAS 2,0025 BARNS (NORMALIZATION AND STANDARDS
SUBCOMMITTEE RECOMMENDED VALUE)
* * * * * * *
CALCIUM EVALUATION - ORNL AUGUST 1971
A COMPLETE REEVALUATION OF CALCUIM NEUTRON AND GAMMA RAY CROSS SECTIONS FROM 0,02 EV TO 20,0 MEV IS PRESENTLY IN PROGRESS AT ORNL, THIS EFFORT WAS UNDERTAKEN TO IMPROVE THE ORIGINAL EVALUATION BY M,K,DRAKE,GULF GENERAL ATOMIC REPORT GA=7829,VOL,4,1967, THE DRAKE EVALUATION WAS ORIGINALY TRANSLATED INTO ENDF FORMAT BY D,J,DUDZIAK, LASL, JULY 1969, REVISED BY P,G,YOUNG, LASL, MAY 1970 AND BEARS MATERIAL NUMBER 540,
THE ORNL REEVALUATION IS NOT COMPLETE AS OF AUGUST 1971, HOWEVER IT WAS POSSIBLE TO MERGE THE WORK DONE TO DATE UP TO 9,0 MEV WITH MAT 540 ABOVE 9,0 MEV, THIS EVALUATION, MAT 1152, IS THE RESULT OF SUCH A MERGING,
THE FOLLOWING FILES AND REACTION TYPE NUMBERS HAVE BEEN TAKEN FROM MAT 540,

FILE	MT		
3	1	UP TO	0,466 MEV
3	16	UP TO	20,000 MEV
3	22	UP TO	20,000 MEV
3	28	UP TO	20,000 MEV
3	102	UP TO	20,000 MEV
3	251	UP TO	20,000 MEV
4	2	UP TO	20,000 MEV
5	16	UP TO	20,000 MEV
5	22	UP TO	20,000 MEV
5	28	UP TO	20,000 MEV
5	91	UP TO	20,000 MEV

CAUTION
****
SINCE WE HAVE FOUND NECESSARY TO ALTER ALL FILES IN MAT 540 BELOW 9,0 MEV,EXCEPT FOR TOTAL CROSS SECTION UP TO 0,466 MEV, CAPTURE CROSS SECTION AND ELASTIC ANGULAR DISTRIBUTIONS, IT IS POSSIBLE THAT WORK IN PROGRESS WILL REVEAL GROSS INADEQUACIES IN THIS EVALUATION ABOVE 9,0 MEV,
COMPLETE DOCUMENTATION FOR THIS EVALUATION WILL ONLY BE AVAILABLE WHEN WE HAVE EXTENDED THE REEVALUATION UP TO 20,0 MEV, HOWEVER, QUESTIONS AND COMMENTS CONCERNING THIS EVALUATION, MAT 1152, ARE WELCOME AND SHOULD BE ADDRESSED TO F,G,PEREY, ORNL,
SEMI-EMPIRICAL PHOTON CROSS SECTION INFORMATION
FROM UCRL 50400

SUMMARY DOCUMENTATION FOR CALCIUM GAMMA-RAY PRODUCTION CROSS SECTIONS

F. G. Perey, C. Y. Fu and W. E. Kinney
Oak Ridge National Laboratory

A complete reevaluation of neutron and gamma-ray production cross section for calcium is underway at ORNL. A previous evaluation for this nuclei was done by M. K. Drake in 1967, Reference 1. The Drake evaluation was originally transferred into ENDF format by D. J. Dudziak, LASL, July 1969 and revised by P. G. Young, LASL, May 1970 and has been assigned ENDF Mat 540. The ORNL reevaluation was not completed as of August 1971, the deadline for consideration of evaluations for ENDF-III. It was, however, possible to improve significantly Mat 540 for reactor shielding applications by incorporating some of the work performed at ORNL. No attempt was made to modify Mat 540 above 9 MeV except for the total cross section. Therefore, full documentation on Mat 1152 above 9 MeV can be found in Reference 1. The major differences of Mat 1152 with Mat 540 are:

1. Total Cross Sections - The total cross sections were completely reevaluated from 460 keV to 20 MeV on the basis of two recent extensive data sets, References 2 and 3. The Karlsruhe, Reference 2, time-of-flight measurement was recently recorrected for residual dead-time errors and has the best energy resolution of the two. The NBS data, Reference 3, was remeasured for this evaluation in an attempt to resolve the differences between a previous NBS measurement and the newly corrected Karlsruhe data. The two recent sets of data still differ by about 20% in the deep minimum

around 550 keV and by a few percent at 14.5 MeV. The evaluation is based mostly on the Karlsruhe data because of the higher energy resolution, but we have renormalized it to the NBS data in the neighborhood of the 550 keV window.

2. Inelastic Cross Sections in 1967 - When Mat 540 was prepared there existed very little inelastic-scattering data for calcium above 5 MeV and our knowledge of level energies and spin-parities for ^{40}Ca was very incomplete. The situation has changed drastically since then. There is now inelastic-scattering data up to 8.5 MeV, Reference 4, and a wealth of information on level energies and spin-parities for ^{40}Ca, Reference 5. For instance, in 1967 only 14 energy levels were known below 8.3 MeV. We now have approximately 50 levels up to this energy with spin-parity assignments and branching ratios for most of them. The inelastic-scattering files in Mat 1152 were generated using the Hauser-Feshbach formalism after having fitted the available data. Cross sections as a function of energy were generated for the lower 17 levels of ^{40}Ca and the first excited state of ^{44}Ca. Inelastic scattering to levels above the 17th one were grouped in groups approximately 250 keV of excitation energy. Above an incident neutron energy of 9 MeV, a continuum representation for inelastic scattering in file MT=91 is the same as in Mat 540.

3. Gamma-Ray Production Cross Sections - As a matter of expediency for ENDF/B-III, the gamma-ray production files were generated under MT=3.

Up to 2 MeV neutron energy the only gamma-ray production mechanism considered is capture. The gamma-ray spectra for capture are based on a decay scheme established on the basis of the thermal data of Reference 6. Gamma-ray production cross sections for (n,n'), (n,p) and (n,α) reactions were computed on the basis of Hauser-Feshbach calculations and the extensive knowledge of branching ratios in the residual nuclei, Reference 5.

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22-TI 1144 ANL TO BE PUBL. MAR71 A.B.SMITH

Titanium

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A. Outline of Data Included

Smooth total, elastic, total inelastic, (n,2n), (n,γ), (n,p) and (n,α) cross sections are given in File 3, along with inelastic excitation cross sections for five levels and the continuum. Values of $\bar{\mu}_L$, ξ and γ derived from the File 4 elastic scattering Legendre coefficients are also given.

File 4 contains elastic scattering Legendre coefficients in the center-of-mass system for 103 energies, along with the transformation matrix. Also File 4 contains angular distributions assumed isotropic in the center-of-mass system for the inelastic data and istropic in the laboratory system for the (n,2n) reaction.

Nuclear temperatures for continuum inelastic and (n,2n) scattering are presented in File 5.

No resonance parameters are given for titanium. A scattering radius yielding a potential scattering cross section of 4.13 barns is given as minimum File 2 data.

B. Sources of Titanium Data

The original ENDF/B titanuim evaluation was prepared as MAT1016 by E. Pennington in 1966 with revisions in 1967. That evaluation was based largely on the compilation by N. Tralli et al., (Ref. 1) of United Nuclear Corporation, which was later slightly modified at AWRE (Ref. 2). Revisions were made in the data of Ref. 1 based on later experimental results, and various additions were made. In 1971 new experimental data and calculations were used by A. B. Smith to prepare a new titanium evaluation which was assigned MAT1144. A description of the data sources is given below.

Total Cross Section

The total cross section up to 100eV was obtained by adding the scattering and capture cross sections. From 100eV to 2.5keV, the σ_{nT} of Ref. 1 was used. From 2.5 to about 100keV, values were obtained from Ref. 3. Experimental results of Whalen and Smith (to be published) were used from 0.1 to 1.5MeV. Above 1.5MeV experimental values from Schwartz (Ref. 4), Barschall et al (Ref. 5) and Foster and Glasgow (Ref. 6) were used.

Elastic Scattering Cross Section

Below 100eV, the elastic cross section of Ref. 1 was used, except that a constant 4.13 barns was assumed below 1.5eV. At all higher energies, σ_{nn} was obtained by subtracting all other partial cross sections from the total. The results agree with the measurements of Smith et al (to be published) when averaged over the experimental resolution.

Inelastic Excitation Cross Sections

At incident energies below about 1.5MeV, recent Argonne experimental results by Smith et al for two levels were used. These cross sections plus cross sections due to excitation of known states at 2.32, 2.44 and 3.29MeV were extrapolated to incident neutron energies of about 7MeV using optical model calculations. The inelastic continuum cross section was also estimated from optical model calculations.

(n,2n), (n,p) and (n,α) Cross Sections

The values of $\sigma_{n,2n}$, σ_{np} and $\sigma_{n\alpha}$ are all based on Ref. 1.

(n,γ) Cross Section

A 1/V capture cross section with a value of 6.1 barns at 0.0253eV, as recommended in Ref. 3, was assumed up to 100eV. From 100eV to 22.5keV, $\sigma_{n\gamma}$ was computed using resonance parameters from Ref. 3 in the single-level

Breit-Wigner formula without Doppler broadening. An assumed Γ_γ of 0.75eV was used. From 22.5keV to about 1MeV, the capture cross section was based on Ref. 3. Values from Ref. 1 were used at higher energies.

$\bar{\mu}_L$, ξ and γ

Values of $\bar{\mu}_L$, ξ and γ were calculated from the elastic scattering Legendre coefficients of File 4.

Elastic Scattering Legendre Coefficients

Elastic scattering Legendre coefficients from about 300keV to 1.5MeV are the experimental results of Smith et al. At lower and higher energies, the coefficients are from Ref. 1, except that optical model calculations were performed to yield coefficients at 14 and 18MeV. The 15×15 transformation matrix from the center of mass to the laboratory system was calculated at Brookhaven.

Continuum Secondary Energy Distributions

Rule-of thumb type estimates were made for the nuclear temperatures for the LF=9 laws for the inelastic continuum and (n,2n) reactions.

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23-V 1017 ANL ANL-7387 (MAR.68) SEP66 E.M.PENNINGTON.J.C.GAJNIAK

III. Vanadium

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A. Outline of Cross Sections Included

Smooth total, elastic, inelastic, (n,2n), (n,γ), (n,p) and (n,α) cross sections are given in File 3, as well as values of μ_L, ξ and γ derived from the Legendre coefficients of File 4. The energy range is 0.001 eV to 15 MeV.

File 4 contains Legendre coefficients in the center of mass system for 42 energies, along with the transformation matrix.

File 5 includes secondary energy distributions for four resolved levels and the continuum in the case of inelastic scattering, along with tabulated nuclear temperatures. Nuclear temperatures are also given for the (n,2n) reaction.

Parameters for the free gas thermal scattering law are in File 7.

No vanadium resonance parameters are given.

B. Sources of Vanadium Data

The present compilation is entirely new, in the sense that it is not based on any previous compilation for reactor calculations. The sources of the vanadium data are described in detail in the following paragraphs.

Total Cross Section

The total cross section below 100 eV was calculated as the sum of scattering and capture cross sections. From 100 eV to about 2 keV,

σ_{nT} was read from the graph in Ref. 1. From 2 keV to 220 keV, values were read from the graphs on p. 23-0-3 and 23-0-4 of Ref. 2. Values from Ref. 1 were then used up to about 0.4 MeV, followed by values from p. 23-0-5 and 23-0-6 of Ref. 2 at higher energies, except for the range from 1.3 to 2.0 MeV in which Ref. 1 values were used.

Elastic Scattering Cross Section

A value of 5 barns was used for the elastic scattering cross section at tabulated energies below 100 eV. At all higher energies σ_{nn} was obtained by subtracting the other cross sections from the total cross section.

(n,γ) Cross Section

The capture cross section was taken as 1/V up to 1.5 eV, based on the value of 5.06 barns at 0.0253 eV recommended in Ref. 2. From 1.5 eV up to 22.5 keV, the capture cross section was calculated from parameters for the first two resonances in V-50 and the first six resonances in V-51 as given in Ref. 2, along with the 1/V contribution required to give agreement with the experimental cross section at 0.0253 eV. The single-level Breit-Wigner formula without Doppler broadening was used. Values of 0.60 and 0.75 eV were assumed for Γ_γ for the V-50 and V-51 resonances, respectively. These values were suggested by Kapchigashev (Ref. 3) to give agreement with his broad resolution measurements of capture cross section shown on p. 23-0-3 of Ref. 2. From 22.5 keV to 2 MeV, the capture cross section was read from the smooth curve for V-51 on p. 23-51-5 of Ref. 2. A 1/E dependence for $\sigma_{n\gamma}$ was assumed at higher energies.

Inelastic Scattering Cross Sections

Inelastic scattering cross sections were calculated up to 2.4 MeV for scattering to four resolved levels in V-51 using the Abacus-2 (Ref. 4,5) and Nearrex (Ref. 6) optical model codes. The optical model parameters used are those of Eq. (8) of Ref. 7. The parameter Q in the Nearrex calculations was taken to be 1.0. Energies of the four resolved levels considered in V-51 are 0.320, 0.930, 1.609 and 1.813 MeV. The spins and parities of the ground state and the first four excited states were taken as 7/2-, 5/2-, 3/2-, 11/2- and 9/2-, respectively (Ref. 8). Since V-50 has an abundance of only 0.24%, it was not considered in the inelastic scattering calculations. From 2.4 MeV to 5.0 MeV the inelastic scattering cross section was arbitrarily extrapolated using the assumption that compound elastic scattering vanished at 5 MeV. At higher energies, the other reaction cross sections were subtracted from the total optical model reaction cross section to yield $\sigma_{nn'}$.

Recent experimental data (Ref. 9,2) for inelastic scattering to the first four resolved levels, for an incident energy of 2.35 MeV only, is in rather good agreement with the calculations as is shown in the table below. Calculations using Q = 0.0 rather than 1.0 in the Nearrex code did not agree quite as well with this experimental data.

Level-MeV	σ-mb (Experimental)	σ-mb (Calculated)
0.320	360±30	369
0.930	160± 8	153
1.609	207±10	207
1.813	145±15	186

(n,2n) Cross Section

The (n,2n) cross section was calculated for V-51 according to the method of S. Pearlstein (Ref. 10) and was then increased by about 20% throughout the entire energy range in order to pass through a single experimental point (Ref. 11). In this calculation, no distinction was made between the laboratory and center of mass systems. This is in contrast to the calculations reported for the molybdenum and gadolinium evaluations in which the distinction between the coordinate systems was treated correctly.

(n,p) Cross Section

A smooth curve was drawn through the experimental V-51 (n,p) Ti-51 points given in Ref. 12. Since the experimental points were measured only at energies well above threshold, the curve was extrapolated downward to an assumed effective threshold of 3 MeV. This value was estimated by inspecting σ_{np} cross sections for other isotopes with Z values near that of vanadium and observing how far effective thresholds are above actual thresholds. The smooth curve on p. 23-51-6 of Ref. 2 is almost in agreement with the σ_{np} values used here in the range above 13 MeV covered by the curve.

(n,α) Cross Section

The (n,α) cross section was read from the smooth curve on p. 23-51-8 of Ref. 2, and extended downwards to an effective threshold of 7 MeV, estimated as for the (n,p) reaction.

μ_L, ξ and γ

Values of μ_L, ξ and γ were calculated from the Legendre coefficients of File 4, as outlined in the documentation of the magnesium cross sections.

Elastic Scattering Legendre Coefficients

Below 1.8 MeV, the Legendre coefficients are based on the experimental results of Langsdorf et al., (Ref. 13), who plot coefficients in the laboratory system as a function of energy. Values were read off these curves, renormalized as in ENDF/B, and transformed to the center of mass system using the transformation matrix routine from the CHAD code (Ref. 14). Since these experimental results include inelastically scattered neutrons, corrections were made above the inelastic scattering threshold, assuming isotropic scattering in the center of mass system. The elastic scattering angular distributions of the Abacus-2 problems were fit at 1.8 MeV and above, using the least-squares fitting routine of the Argonne SAD code (Ref. 15). From 2.6 through 4.0 MeV, the coefficients were adjusted using an estimated compound elastic scattering cross section, assumed isotropic in the center of mass system. At 5 MeV and above, it was assumed that compound elastic scattering is negligible. Since 12 Legendre coefficients are used at high energies, a transformation matrix from the center of mass to laboratory system including terms through ℓ = 12 is contained in File 4.

Secondary Energy Distributions

The probabilities of exciting each of the four resolved inelastic levels of the Abacus-2 Nearrex calculations are tabulated from threshold to 2.4 MeV. Nuclear temperatures calculated from the

Yiftah-Okrent-Moldauer prescription (Ref. 16), are given at 2.4 and 15 MeV as the variation is linear on a log-log scale.

Thermal Neutron Scattering Law

A free gas thermal neutron scattering law was assumed. The cutoff above which the static model is used was taken to be 1.5 eV, and a free atom scattering cross section of 5.0 barns was used.

C. Comments on Vanadium Cross Sections

The recent measurements of $\sigma_{n\gamma}$ by Kapchigashev (Ref. 3) have helped to reduce the uncertainty in the capture cross section in the resonance region. Experimental data on inelastic scattering is available only at 2.35 MeV (Ref. 9,2), but the good agreement between this data and the optical model calculations does give some confirmation of the validity of the calculations. There is uncertainty in the (n,p) and (n,α) cross sections at low energies since the data had to be extrapolated downward from higher energies, with the extrapolation covering a rather large range in the case of the (n,p) cross section. No elastic angular distribution measurements exist above 1.8 MeV. However, optical model calculations of elastic angular distributions are generally rather reliable above a few MeV.

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24-CR 1121 WNES.BNL WCAP-7281(1969) JUL70 AZZIZ.CORNYN(WNES) DRAKE(BNL)

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                    ENDF/B MATERIAL NO= 1121
CHORMIUM  WNES=BNL    EVAL=1969   N.AZZIZ AND J.CORNYN (WNES)
WCAP-7281             DIST=JUL70  REV-JUL70
*         *           *          *          *          *          *
NATURAL CHROMIUM
EVALUATED BY  N.AZZIZ AND J.CORNYN (WEST.) PLUS DRAKE (BNL)
*         *           *          *          *          *          *
ORIGINAL DATA WAS MAT =      1107
DATA WAS MODIFIED JULY, 1970 TO CONFORM TO ENDF/B-II FORMATS
ALSO DATA FOR THE TOTAL, ELASTIC SCATTERING, AND RADIATIVE
CAPTURE CROSS SECTIONS WERE REPLACED
FOR NEUTRONS ENERGIES LESS THAN 650  KEV  *          *          *
DATA SOURCE= BELOW 350KEV RPI-1970(STIEGLITZ)
DATA SOURCE= ABOVE 350KEV DUKE 1962 (BOWMAN ET,AL.)
DAYA ARE REPRESENTED BY SLBW RESOLVED RESONANCE
PARAMETERS PLUS A SMOOTH BACKGROUND IN FILE 3,
*         *           *          *          *          *          *
CHROMIUM
EVALUATED BY N, AZZIZ AND J, CORNYN, 1967, AT WAPD,
RE-EVALUATED BY N, AZZIZ AND J.W.CONNELLEY, 1969, AT WAPD,
AND DRAKE AT BNL,FOR DETAILS SEE N, AZZIZ,WCAP7281,

3,1
  1,2,3,4,5,6,7,8,9
P,2
  TAKEN AS SIGMAEL  SIGMATOTAL- SIGMAN,GAMMA- SIGMANONEL
3,3
  SUM OF REACTIONS 4,16,106,107, WITH CONTRIBUTIONS FROM (N,NP),
  (N,D),ETC
3,4
  17,18,23
3,16
  19,20,23
3,102
  10,11,12,13
3,103
  21,22,23
3,107
  23
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25-MN-55 1019 BNL BNL-50060 (JUN.67) JUN67 STEPHENSON.PRINCE.PEARLSTEIN

Principal Sources of ENDF/B Data for Mn-55, MAT 1019

by

T.E. Stephenson, A. Prince, and S. Pearlstein

I. INTRODUCTION

This report describes the collection and choice of Mn-55 data placed in the proper format for the Evaluated Nuclear Data File - Version B, ENDF/B. The description of how the evaluation was performed is contained in Sections III and IV. Section III deals with the manganese cross section below 80 keV, and Section IV deals with the manganese cross section from 80 keV to 20 MeV.

II. GENERAL INFORMATION

The decay data for File 1 were taken from the Chart of the Nuclides.(1) The ratio of the manganese atomic mass to that of the neutron (54.566) is based on data taken from the Handbook of Chemistry and Physics.(2)

III. LOW ENERGY CROSS SECTIONS

The total and partial cross sections from 0.001 eV to 80 keV can be calculated from the resonance parameters of 27 levels as recorded on the ENDF/B tape, using the Breit-Wigner multilevel scattering formula. When the single level Breit-Wigner formalism is used, as required in the present version of ENDF/B, it is necessary to add a smooth, elastic cross section, which is simply the resonance-resonance interference cross section. Above 8.95 keV another smooth cross section is added, this one for absorption.

We found that the capture cross section calculated from the resonance parameters from 10 keV to 80 keV gave a capture resonance integral which was $\sim$ 20% of that which can be computed from broad resolution measurements of the capture cross section within this energy interval. We therefore have added a smooth capture cross section which is $\sim$ 80% of the experimental measurements in this region.

A. <u>Resonance Parameters</u>

Parameters for the 27 levels are given in Table I. References for 21 of the levels are given in the Table. Parameters for the remaining six were generated at BNL.[3] The bound level parameters were determined by the requirements of fitting the total cross section and giving the correct thermal absorption cross section. Parameters for the four levels in the 30 keV region were calculated in order to fit the measured total cross section in the vicinity of the spin doublet. Morgenstern, et al.,[4] give a $g\Gamma_n$ = 1500±200 for the doublet. Our parameters, including the narrow resonance at 36,450 eV, give a combined $g\Gamma_n$ of 1327 eV, which is within Morgenstern's error bar.

B. <u>Thermal Cross Sections</u>

The effective scattering radius, 4.54 fermis, was selected on the basis of giving the best over-all fit. Tests of the correctness of the resonance parameters and the scattering radius, in addition to that effected by the over-all fit, are comparisons of the calculated values of the thermal absorption cross section, the low energy scattering cross section, and the coherent scattering cross section with measured values of these quantities. Our value for $\sigma_{a,th}$ = 13.4 barns is within the error bar of the value recommended[5] from experimental measurements, 13.3±0.1 b. There is some energy dependence in the low energy calculated scattering

TABLE I

MANGANESE

RESONANCE PARAMETERS

J	E_o (eV)	Γ_n (eV)	Γ_n^o (eV)	Reference
2	335.5	22.4		R.E. Coté, L.M. Bollinger, and G.E. Thomas, Phys. Rev. 134, B1048 (1964)
3	1098	14.6		
3	2355	404		
2	7110	425		
3	8740	370		
(3)	17774	11		J. Morgenstern, S. de Barros, G. Bianchi, C. Corge, V. D. Huynh, J. Julien, G. Le Poittevin, F. Netter, and C. Samour, International Conf. on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium (July 19-23, 1965)
(2)	17945	65		
3	20910	860		
2	23640	380		
2	26370	120		
3	26910	380		
3	40980	280		
2	53280	80		
3	57380	420		
2	58060	950		
2	59480	750		
3	64130	800		
3	66460	120		
2	69470	170		
3	70000	270		
2	73880	1000		
2	30400	23		
2	34650	1200		
3	35300	1400		
2	36450	26		
3	-4700		6.9	
2	-3300		4.73	

cross section. However, the value calculated in the 7-20 eV range is in agreement with the recommended value[6] of 2.0±0.1 b. The recommended value is for the bound atom cross section; the Breit-Wigner formula computes the free atom cross section. For example, our calculated scattering cross section at 10 eV, 1.87 b, when multiplied by the factor $(A+1/A)^2$, gives 1.94 b, which is within the error bar of the recommended value. Below ~ 7 eV the scattering cross section decreases gradually, reaching 1.8 b (including the reduced mass correction). Above ~ 20 b the scattering cross section increases due to the 335.5-eV resonance. The calculated value of the coherent scattering cross section, 1.71 b, is in good agreement with the value recommended[6] from experiment, 1.7±0.1 b.

C. Resonance Integrals

We have chosen 0.52 eV as the value of the radiation width. When this value of Γ_γ is used to calculate the absorption resonance integral, we obtain I_a = 15 b, a result which is in agreement with the recent measurement of Louwrier and Aten.[7] There are many measurements of the resonance integral and as many values.[8] We have chosen the results from Ref. 7 because the description of the method appeared to promise accurate results. The cadmium cutoff for our calculation is taken as 0.56 eV, as was done in Ref. 7.

The calculated value of the scattering resonance integral is 556 barns. The only reported measurement by Harris, et al.,[9] is 509 barns.

IV. HIGH ENERGY CROSS SECTIONS

A. Optical Model Parameters

Optical model calculations using ABACUS II[10] were carried out to determine the total, elastic, inelastic, and differential scattering cross sections from 100 keV to 20 MeV.

The optical model potential was given by[11]

$$V(r) = -V_{RE}\, f(r) - i\, V_{IM}\, g(r) - V_{SR}\, h(r)\, \bar{\ell} \cdot \bar{\sigma} ,$$

where V_{RE}, V_{IM}, and V_{SR} are the real, imaginary, and real spin-dependent potentials, respectively; f(r), g(r), and h(r) are their radial variation; and $\bar{\sigma}$ is the Pauli spin operator.

The radial variations of the potentials were assumed to have the following forms[11]:

f(r) - Saxon-Wood

g(r) - Gaussian Surface

h(r) - Thomas

In order to obtain satisfactory agreement with available experimental data, it was necessary to use two sets of optical model parameters. The potentials were explicit functions of energy given by:

Set A

$$V_{RE} = \begin{cases} 47.2 \text{ (MeV)} & E_n \le 1 \text{ MeV} \\ 47.2\text{-}0.318\, E_n \text{ (MeV)} & E_n > 1 \text{ MeV} \end{cases}$$

$$V_{IM} = \begin{cases} 6 \text{ (MeV)} & E_n \le 0.1 \text{ MeV} \\ 6 + 0.75\, E_n \text{ (MeV)} & 0.1 < E_n \le 4 \text{ MeV} \\ 8.2 + 0.2\, E_n \text{ (MeV)} & E_n > 4 \text{ MeV} \end{cases}$$

$$V_{SR} = \begin{cases} 9.5 \text{ MeV} & E_n \le 1 \text{ MeV} \\ 9.5\text{-}0.636\, E_n \text{ (MeV)} & E_n > 1 \text{ MeV} \end{cases}$$

$$a = \begin{cases} 0.65 \text{ (fermi)} & E_n \le 4 \text{ MeV} \\ 0.70 \text{ (fermi)} & E_n > 4 \text{ MeV} \end{cases}$$

$$b = 0.98 \text{ (fermi)}$$

$$r_o = 1.25\, A^{1/3} \text{ (fermi)}$$

$$\text{Set B} \begin{cases} V_{RE} = & 52.5 - 0.6\, E_n \text{ (MeV)} & r_o = 1.25\, A^{1/3} \text{ (fermi)} \\ V_{IM} = & 2.5 + 0.3\, E_n \text{ (MeV)} & a = 0.65 \text{ (fermi)} \\ V_{SR} = & 10 - 0.15\, E_n \text{ (MeV)} & b = 0.98 \text{ (fermi)} \end{cases}$$

E_n = neutron energy in MeV A = Mass Number

In the discrete level energy range (threshold to 2 MeV), Set B was used to calculate the excitation cross section of the very low 0.126-MeV level, while the higher level excitation cross sections were calculated with Set A.

The energy level diagram is shown in Table II (below) and is based on the work of Refs. 12-14. The spins and parities of all levels above 0.126 are still somewhat in doubt.

TABLE II

Energy Levels for Mn-55

MeV	I^{π}
1.884	$(5/2^-)$
1.527	$(3/2^-)$
1.289	$(11/2^-)$
0.983	$(9/2^-)$
0.126	$7/2^-$
0	$5/2^-$

B. Total Cross Section, σ_T

In the low energy region (E < 1.0 MeV), the manganese total cross section shows pronounced gross structure fluctuations; therefore the optical model calculations were adjusted so as to agree with the smooth cross sections averaged over the resonances. For E > 1 MeV the optical model yielded very good results.

C. Elastic Scattering, $\sigma_{e\ell}$

For E ≤ 1.0 MeV the total elastic and differential elastic cross sections from the optical model calculations were corrected such that

$$\sigma_{e\ell} = \sigma_T - \sigma_{ne} \quad ,$$

where

$$\sigma_{ne} = \sigma_{nn'} + \sigma_{n\gamma} \quad \text{for } E < 1 \text{ MeV}$$

and σ_T was the averaged total cross section described earlier. For E > 1.0 MeV the shape elastic cross sections given by the optical model were assumed to be correct and the calculated compound elastic scattering cross section was corrected primarily to account for the competition arising from the inelastic excitations. Beyond 6 MeV this correction was practically nil. In general,

$$\sigma_{e\ell} = \sigma_T - \begin{cases} \sigma_{n\gamma} & E < 0.13 \text{ MeV} \\ \sigma_{nn'}+\sigma_{n\gamma} & 0.13 \le E < 4 \text{ MeV} \\ \sigma_{nn'}+\sigma_{n\gamma}+\sigma_{np} & 4.0 \le E < 9 \text{ MeV} \\ \sigma_{nn'}+\sigma_{n\gamma}+\sigma_{np}+\sigma_{n\alpha} & 9 \le E < 10.5 \text{ MeV} \\ \sigma_{nn'}+\sigma_{n\gamma}+\sigma_{np}+\sigma_{n\alpha}+\sigma_{n,2n} & E > 10.5 \text{ MeV} \end{cases}$$

In the low energy region, due to the extreme fluctuations in the cross sections no normalization of the calculated distribution to the experimental data was made, and any agreement in this region must be considered fortuitous.

As pointed out by A. B. Smith,[15] the elastic scattering in the energy region about 0.9 MeV is subject to violent changes due to the resonant structure, and since his incident energy is uncertain by 20 keV, different measurements are obtained in the energy range of 900±20 keV. This is adequate reason not to resort to a parameter search routine for a "consistent" set of optical model parameters. The agreement between calculation and experiment at 3.0 MeV is rather good, and one might then hope that above this energy the calculated values provide an adequate description of the angular distributions.

The elastic differential scattering cross section was converted by CHAD[16] into Legendre coefficients. This program also produced $\bar{\mu}_L$, the average cosine of the scattering angle in the laboratory system, and ξ, the average logarithmic energy decrement per elastic collision, and the matrix for transforming from the center-of-mass to the laboratory system.

D. Nonelastic Cross Sections, σ_{ne}

Up to 2 MeV, $\sigma_{ne} = \sigma_{nn'} + \sigma_{n\gamma}$. Beyond this region (inelastic continuum), σ_{ne} was adjusted so as to agree with the shape of Fe.[5] This adjustment was necessary due to the low lying 0.126 level in Mn-55, as compared with the first level of 0.845 MeV in Fe.

E. Radiative Capture, $\sigma_{n\gamma}$

Quite a bit of experimental data exists for $\sigma_{n\gamma}$ in manganese[5, 17] in the high energy region up to 20 MeV. SAUDEX,[18] a computer program based on the theory of Lane and Lynn,[19] was used to produce the s- and p-wave contributions to the total capture cross section in the keV region. From the low energy resonance data the s- and p-wave strength functions were calculated to be $s_0 = s_1 = 4.5 \times 10^{-4}$. These produced excellent agreement up to about 50 keV, where deviations from the experimental data began to show due to higher ℓ-wave contributions and the onset of competition with inelastic scattering at 0.13 MeV. The peak in the experimental capture cross section[20] around 15.0 MeV is in agreement with the prediction of Lane's[20] "collective capture" model.

F. Inelastic Cross Section, $\sigma_{nn'}$

The inelastic cross section was calculated in the discrete energy region (E < 2.0 MeV) with the Hauser-Feshbach interpretation,[21] and the partial excitation cross sections were compared with Ref. 5 and A. B. Smith's[15] experimental data on the 0.126-MeV level. The calculated value for excitation of the 0.126-MeV levels, although falling within the low side of Smith's data, appears to be somewhat less than that depicted in Refs. 5 and 22. This possibly could be improved by employing a width fluctuation correction factor to the Hauser-Feshbach formula as described by P. A. Moldauer,[23] in which case another set of optical potential parameters might be necessary. For the levels above the 0.126 level, the agreement with experimental data[12] was excellent, despite the uncertainty of the spins and parities. In the continuum region (E > 2.0 MeV) the inelastic cross section was determined from

$$\sigma_{nn'} = \sigma_{ne} - (\sigma_{np} + \sigma_{n\alpha} + \sigma_{n\gamma} + \sigma_{n,2n}) .$$

G. $\sigma_{n,p}$ Cross Section

The experimental data for this reaction in the 14-MeV region differs considerably, ranging from 30 mb to 110 mb.[5, 25, 26] Since the n,p threshold is approximately 2 MeV for Mn-55 and 3 MeV for Fe-56, the larger of the experimental values was chosen on the grounds of systematic consistency with Fe-56. Thus the $\sigma_{n,p}$ cross section for Mn-55 was determined from threshold to 20 MeV by shape normalization to $\sigma_{n,p}$ of Fe-56.[5]

H. $\sigma_{n,\gamma}$ Cross Section

Although the threshold for this reaction is rather low (E $\approx$ 0.7 MeV), the extrapolated experimental data[5] was assumed to be insignificant below E = 9.0 MeV. Recent experimental data by Minetti, et al.,[25] are in general agreement with those indicated in Ref. 5.

I. $\sigma_{n,2n}$ Cross Section

Values of the n,2n cross section were taken from the work of Pearlstein.[24]

J. Composite Cross Section

The nuclear temperature for inelastically scattered neutrons is about 1.0 MeV and 0.5 MeV for the secondary neutrons.[27]

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                     ENDF/B MATERIAL NO= 1180
IRON      ORNL       EVAL-1970  PENNY,KINNEY,WRIGHT,PEREY,FU
ORNL-4617(1970)      DIST-JAN72 REV-DEC71
*         *          *          *          *          *          *
DATA MODIFIED JAN,1972
THE 2200 M/SEC CROSS SECTION WAS CHANGED TO 2,56 BARNS TO
CONFORM TO THE CSEWG NORMALIZATION AND STANDARDS SUBCOMMITTEE
RECOMMENDED VALUE, ALL LOW ENERGY RADIATIVE CAPTURE CROSS
SECTIONS WERE MODIFIED BELOW 500 EV TO BE CONSISTENT
*         *          *          *          *          *          *
NATURAL IRON- MOD, 2            DEC, 1971
*         *          *          *          *          *          *
ATURAL IRON-MOD, 2-DEC, 1971-ORNL-PENNY-KINNEY-WRIGHT-PEREY-FU


          DETAILS OF THE EVALUATION ARE REPORTED IN
   S,K, PENNY AND W,E, KINNEY, A RE-EVALUATION OF NATURAL IRON
   NEUTRON AND GAMMA-RAY-PRODUCTION CROSS SECTIONS, ENDF/B MATER-
   IAL 1124, ORNL-4617  ENDF-139   1970

    IN MOD, 2 THE GAMMA-RAY PRODUCTION FILES HAVE BEEN MODIFIED
    TAKING INTO ACCOUNT THE DATA OF ORPHAN AND HOOT, REF, 50,


FILE 2 RESONANCE PARAMETERS
     MULTILEVEL BREIT-WIGNER PARAMETERS ARE GIVEN FOR FE-54; FE-56
     , AND FE-57 FOR THE ENERGY RANGE 1-60 KEV,
     REFS, 1 AND 2,
FILE 3 NEUTRON CROSS SECTIONS
   SECTION 1 TOTAL INTERACTION
       ,00001 EV TO 330 KEV --- REFS, 1, 2, AND 3,
       BACKGROUND CORRECTIONS FOR THE 24-KEV WINDOW HAVE BEEN EN-
       TERED TO RAISE THE MINIMUM TO 425 MBNS,----PRELIMINARY RE-
       SULTS FROM ORELA MEASUREMENTS OF JACK HARVEY ET AL,
       330 KEV TO 15 MEV --- REFS, 4, 5, 6, AND 7,
   SECTION 2 ELASTIC SCATTERING
       DERIVED BY SUBTRACTING THE NON-ELASTIC CROSS SECTION FROM
       THE TOTAL CROSS SECTION,
   SECTION 3 NON-ELASTIC INTERACTION
       DERIVED BY ADDING THE TOTAL INELASTIC SCATTERING,  N;2N ,
       CAPTURE,  N,A , AND  N,P  CROSS SECTIONS,
   SECTION 4 TOTAL INELASTIC SCATTERING
       DERIVED BY ADDING INELASTIC SCATTERING CROSS SECTIONS FOR
       EXCITING DISCRETE LEVELS AND THE CONTINUUM OF LEVELS,
   SECTION 16  N,2N  REACTION
       REF, 8
   SECTION 51 INELASTIC SCATTERING EXCITING FIRST LEVEL IN FE-56
       0,8611 MEV TO 1,5 MEV --- REFS, 8 AND 9,
       1,5 MEV TO 2,122 MEV --- REFS, 9 AND 10,
       2,122 MEV TO 15 MEV --- REFS, 11 - 19, 47, AND 48,
   SECTION 52 INELASTIC SCATTERING EXCITING FIRST LEVEL IN FE-54
       REF, 4
   SECTION 53 INELASTIC SCATTERING EXCITING SECOND THROUGH
    /THROUGH/       NINETEENTH LEVELS IN FE-56,
   SECTION 70
       REFS, 11 - 19, 47, AND 48,
   SECTION 91 INELASTIC SCATTERING EXCITING THE CONTINUUM
       REFS, 11 AND 20,
   SECTION 102 RADIATIVE CAPTURE
       Q-VALUE IS AVERAGED WITH THERMAL CROSS SECTIONS,
       REFS, 1 AND 2,
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SECTION 103 N,P REACTION
Q-VALUE IS AVERAGED WITH ABUNDANCES.
REFS. 3 AND 4.
SECTION 107 N,A REACTION
Q=VALUE IS AVERAGED WITH ABUNDANCES.
REFS. 3 AND 4.
SECTION 251 MU BAR
DERIVED FROM ELASTIC SCATTERING ANGULAR DISTRIBUTIONS AND KINEMATICS USING THE COMPUTER PROGRAM SAD.
SECTION 252 XI
SEE SECTION 251.
SECTION 253 GAMMA
SEE SECTION 251.

FILE 4 ANGULAR DISTRIBUTIONS OF SECONDARY NEUTRONS
ALL DISTRIBUTIONS ARE GIVEN IN THE CENTER OF MASS SYSTEM IN THE LEGENDRE POLYNOMIAL REPRESENTATION.
SECTION 2 ELASTIC SCATTERING
.00001 EV TO 1.23 MEV --- REFS. 21, 22, AND 23.
1.23 MEV TO 4 MEV --- REFS. 11, 12, AND 24 THROUGH 34.
4 MEV TO 15 MEV --- REFS. 11, 12, AND 24.
TRANSFORMATION MATRIX GIVEN WAS CALCULATED USING THE COMPUTER PROGRAM SAD.
SECTION 16 N,2N REACTION
BOTH NEUTRONS ARE ASSUMED TO BE ISOTROPIC.
SECTION 51 INELASTIC SCATTERING EXCITING FIRST LEVEL IN FE-56
REFS. 11 THROUGH 19.
SECTION 52 INELASTIC SCATTERING EXCITING FIRST LEVEL IN FE-54
ASSUMMED ISOTROPIC.
SECTION 53 INELASTIC SCATTERING EXCITING SECOND THROUGH
/THROUGH/ NINETEENTH LEVELS IN FE-56.
SECTION 70
REFS. 11 THROUGH 19.
SECTION 91 INELASTIC SCATTERING EXCITING THE CONTINUUM
ASSUMMED ISOTROPIC --- REF. 11.

FILE 5 ENERGY DISTRIBUTIONS OF SECONDARY NEUTRONS
SECTION 16 N,2N REACTION
REF. 49.
SECTION 91 INELASTIC SCATTERING EXCITING THE CONTINUUM
THERE ARE TWO LAWS FOR THIS SECTION NAMELY, A MAXWELLIAN DISTRIBUTION, WHICH HAS A NON-ZERO PROBABILITY ONLY AFTER 7.2 MEV INCIDENT NEUTRON ENERGY, AND AN ARBITRARY TABULATED DISTRIBUTION. --- REFS. 11, 47, AND 48.

FILE 12 MULTIPLICITIES OF GAMMA RAYS PRODUCED BY NEUTRON REACTIONS
THERE IS NO REPETITION OF GAMMA RAYS IN THIS FILE. TO ACCOUNT FOR ALL GAMMA RAYS ONE MUST TAKE THE JOIN OF ALL SECTIONS.
SECTION 3 NON-ELASTIC INTERACTION
THESE GAMMA RAYS ARE FROM N,N* , N,A , AND N,P REACTIONS IN FE-56. THE REPRESENTATION IS A CONTINUUM DISTRIBUTION AND THE NEUTRON ENERGY RANGE IS 2.122 MEV TO 15 MEV.
REFS. 11 THROUGH 19, 35, 36, 37, AND 50.
SECTION 16 N,2N REACTION
THESE GAMMA RAYS ARE TREATED AS A CONTINUUM DISTRIBUTION.
SECTION 51 INELASTIC SCATTERING EXCITING FIRST LEVEL IN FE-56
NEUTRON ENERGY RANGE IS 0.8611 TO 2.122 MEV. ONE DISCRETE GAMMA RAY IS GIVEN.
SECTION 52 INELASTIC SCATTERING EXCITING FIRST LEVEL IN FE-54
ONE DISCRETE GAMMA RAY IS GIVEN.
SECTION 102 RADIATIVE CAPTURE
THESE GAMMA RAYS ARE REPRESENTATIVE OF NEUTRON ENERGY RANGES. THE LAST RANGE STRICTLY EXTENDS ONLY TO 1 MEV BUT

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IS ASSUMMED TO EXTEND TO 15 MEV, THE GAMMA RAYS ARE TREATED AS A CONTINUUM DISTRIBUTION,
REFS, 1, 2, 15, 18, AND 38 THROUGH 44,

FILE 14 ANGULAR DISTRIBUTIONS OF SECONDARY GAMMA RAYS
THE SECTIONS CORRESPOND TO THE SECTIONS IN FILE 12 AND IT IS ASSUMED THAT ALL THE DISTRIBUTIONS ARE ISOTROPIC,

FILE 15 ENERGY DISTRIBUTIONS OF SECONDARY GAMMA RAYS,
THE DISTRIBUTIONS ARE HISTOGRAMS WITH UNIFORM GAMMA RAY ENERGY WIDTHS OF 50 KEV, --- REFS, SEE FILE 12

FILE 23 PHOTON INTERACTION CROSS SECTIONS
REFS, 45 AND 46,
SECTION 501 TOTAL INTERACTION
SECTION 502 COHERENT SCATTERING
SECTION 504 INCOHERENT SCATTERING
SECTION 516 PAIR PRODUCTION PLUS TRIPLET PRODUCTION
SECTION 602 PHOTOELECTRIC INTERACTION

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27-CO-59 1118 BNL TO BE PUBL. 1971 T.E.STEPHENSON. A.PRINCE

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DIST=JAN72 REV-JAN72

* * * * * * *

COBALT-59

EVALUATORS A. PRINCE, T. E. STEPHENSON

GENERAL INFORMATION

DECAY DATA FROM CHART OF NUCLIDES BY D.GOLDMAN AND J.ROESSER(1966)
RATIO M SUB CO TO M SUB N ALSO FROM CHART OF NUCLIDES
2200 M/SEC CROSS SECTIONS N,G= 37.20 BARNS, SCATTERING = 6.802 B
POT.SCAT.=5.3098

RESOLVED RESONANCE PARAMETERS

RESOLVED RESONANCE REGION EXTENDS FROM E-05 EV TO 36 KEV.
35 S-WAVE AND 5 P-WAVE POSITIVE ENERGY LEVELS SELECTED FROM THE LITERATURE WERE USED AS A STARTING POINT IN FITTING TOTAL CROSS SECTION DATA TO THE BREIT-WIGNER MULTILEVEL SCATTERING AND SINGLE LEVEL CAPTURE FORMULAE AS PROGRAMMED IN SIGPLOT. PARAMETERS FOR 2 BOUND LEVELS CONSTRUCTED TO IMPROVE FIT TO (1) LOW ENERGY TOTAL CROSS SECTION DATA, (2) THERMAL CAPTURE DATA, AND (3) THERMAL PO-LARIZATION DATA. OTHER PARAMETERS ADJUSTED AS NEEDED DURING THE FITTING PROCESS.DATA REFERENCES INCLUDE (1) D.J.HUGHES AND R.B.SCHWARTZ, NEUTRON CROSS SECTIONS, BNL 325, 2ND ED. (JULY 1. 1958). AND M.GOLDBERG ET AL. BNL-325.2ND ED. SUPP. NO.2 (FEB.1966) (2) J. STORY,ON THE THERMAL CAPTURE CROSS SECTION OF COBALT, AEEW-R597 (1968), AND M.GOLDBERG,OP.CIT., AND (3) R.SCHERMER, SPIN DE-PENDANCE OF THE THERMAL NEUTRON CROSS SECTION OF CO-59, PHYS. REV. 130 1907 (1963). REFERENCES FOR RESONANCE PARAMETERS INCLUDE M.GOLDBERG, OP.CIT., J.GARG,ET AL. CR-1860 (1964). AND J.MORGEN-STERN,ET AL. NUC.PHYS. A122,602 (1967). VALUE OF THE POTENTIAL SCATTERING RADIUS IS 6.5F. LEVELS HAVING NO EXPERIMENTALLY MEAS-URED RADIATION WIDTH HAVE BEEN ASSIGNED GAMMA SUB GAMMA = 0.4 EV.

SMOOTH CROSS SECTIONS

FILE 3 CROSS SECTIONS IN THE RESOLVED RESONANCE REGION ARE ZERO OR SMALL. THE ELASTIC SCATTERING CROSS SECTION FROM 36 TO 200 KEV BASED ON WORK OF GARG ET AL (OP CIT) AND IS JOINED TO OPTICAL MODEL RESULTS AT 200KEV. CAPTURE CROSS SECTION IS JOINED TO OPTICAL MODEL RESULTS AT 36KEV.
MU-BAR,XI, AND GAMMA CALCULATED BY PROGRAM MATRIX.

ANGULAR DISTRIBUTIONS OF SECONDARY NEUTRONS

ANGULAR DISTRIBUTIONS FOR ELASTICALLY SCATTERED NEUTRONS GIVEN BY LEGENDRE COEFFICIENTS CALCULATED IN CM SYSTEM BY CHAD. THE TRANS-FORMATION MATRIX, CALCULATED BY PROGRAM MATRIX, IS GIVEN. DISTRI-BUTIONS FOR INELASTIC DISCRETE LEVEL AND CONTINUUM SCATTERING ARE GIVEN AS ISOTROPIC NORMALIZED PROBABILITY DISTRIBUTIONS IN THE CM SYSTEM.

SECONDARY ENERGY DISTRIBUTION

NUCLEAR TEMPERATURES FOR EMISSION OF FIRST AND SECOND NEUTRONS AT E SUB N = 14.8 MEV TAKEN FROM EXPERIMENT, S.C. MATHUR ET AL. PHYS. REV. 186, P.166,(OCT.69). TEMPERATURES AT OTHER ENERGIES ARE CALCULATED VALUES.

THERMAL NEUTRON SCATTERING LAW

FREE ATOM SIGMA= 6.802B, OBTAINED BY RESONANCE PARAMETER FIT.

28-NI 1123 WNES.BNL WCAP-7387 (1969) JUN71 AZZIZ.CORNYN(WNES) DRAKE(BNL)

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                 ENDF/B MATERIAL NO= 1123
NICKEL    WNES=BNL   EVAL=1969  N.AZZIZ AND J.CORNYN(WNES)
WCAP-7281            DIST=JUL70 REV-SEP71
*      *        *        *        *        *        *
NATURAL NICKEL
EVALUATED BY N.AZZIZ AND J.CORNYN (WEST.) PLUS DRAKE (BNL)
       *        *        *        *        *
DATA MODIFICATIONS MADE SEPT.1971
1. ERROR CORRECTED IN FILE 3, MT=102 AT 1.0E-05 EV
2. BACKGROUND CAPTURE CROSS SECTION (9.0 TO 25.0 KEV) REDUCED TO
   BE IN AGREEMENT WITH HOCKENBURY,ET.AL.,PHYS.REV.178,1746(1969)
3. MT=28 (N,NP) CROSS SECTION ADDED. DATA BASED ON MEASUREMENTS
   GIVEN IN BNL-325(2ND ED)SUPPL-2,VOL-IIA. SHAPE BASED ON CALC.
   DONE BY S.PEARLSTEIN
       *        *        *        *        *
*      *        *        *        *        *        *
ORIGINAL DATA WAS MAT =     1109
DATA WAS MODIFIED JULY, 1970 TO CONFORM TO ENDF/B-II FORMATS
ALSO DATA FOR THE TOTAL, ELASTIC SCATTERING, AND RADIATIVE
CAPTURE CROSS SECTIONS WERE REPLACED
DATA SOURCE  BELOW 650 KEV RPI 1970(STEIGLITZ)(SIGMA N,G)
DATA SOURCE  BELOW 100 KEV BNL325  (SIGMA TOTAL)
DATA SOURCE  100-650 KEV   DUKE    (SIGMA TOTAL)
DATA ARE REPRESENTED BY SLBW RESOLVED RESONANCE
PARAMETERS PLUS A SMOOTH BACKGROUND IN FILE 3.
*      *        *        *        *        *        *
NI
EVAL.BY AZZIZ AND CONNELLEY(WAPD)AND DRAKE(BNL)1970
FOR DETAILS SEE WCAP 7281.
3,1
 2,3,4,5,6,7,8,9,23
3,2
 REACTION 3,1 MINUS REACTIONS  3,3 AND 3,102
3,3
 SUM OF REACTIONS 3,16, 3,103, 3,107, 3,4, AND 3,102
 ACCOUNT IS TAKEN OF (N,D),(N,NP), ETC.
3,4, 5,4
 21,22
3,16
 25,26
3,102
 11,12,13,14
3,103
 27,28,29
3,107
 30
4,2
 17,18,21
REFERENCES
1.R.GROUCHOWSKI,A.D.TROUBETZKEY, ANL-5139(1965).
2.J.RAINWATER,J.B.GARG,N.W.HAVENS,JR.,BULL.AMER.PHYS.SOC.8,
  334(1963).
3.C.T.HIBDON,PHYS.REV.108,414.
4.J.F.WHALEN, ANL-7210 (1966).
5.J.CARE,M.LAURAT,P.YOCN (1963,SEE BNL 325).
6.A.B.SMITH (1965,SEE BNL 325).
7.A.B.SMITH, WASH-1057 (1965).
8.D.W.MILLER,R.K.ADAIR,C.K.BOCKELMAN,S.E.DARDEN,PHYS.REV.88,
  83(1952).
9.D.G.FOSTER,D.W.GLASGOW (1965,1967, SEE BNL 325).
10.G.J.MCCALLUM,G.S.MANI,A.T.G.FERGUSON,NUC.PHYS.16,313(1960).
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ENDF/B MATERIAL NO= 1123

11,S,V,KAPCHIGASHEV,YU,P,POPOV,ATOM,ENER,15,120(1963),
12,J,H,GIBBONS,R,L,MACKLIN,P,D,MILLER,J,H,NEIHR,PHYS,REV,122,
182(1961),
13,YU,YA,STAVISSKII,A,V,SHAPAR,ATOM,ENER,10,264(1961),
14,B,C,DIVEN,J,TERRELL,A,HEMMENDINGER,PHYS,REV,120,556(1960),
15,BNL 325,SUPPL,2,VOL,IIA(1966),
16,J,J,SCHMIDT,KFK 120(EANDC-E-35U)(1966),
17,ALDERMASTON WINFRITH NUCLEAR DATA FILE/64,
18,S,A,COX,CONF 250-13(1962),
19,BNL 400
20,P,H,STELSON,R,L,ROBINSON,H,J,KIM,J,RAPAPORT,G,R,SATCHLER,
NUC,PHYS,68,97(1965),
21,D,L,BRODER,V,E,KOLESOV,A,I,LASHUK,I,P,SADOKHIN,A,G,DOVBENKO,
ATOM,ENER,16,103(1964),
22,TOWLE,ET,AL,(1964,SEE REF, 24)
23,E,G,BILPUCH,K,K,SETH,C,D,BOWMAN,R,H,TABONY,R,C,SMITH,H,W,
NEWSON,ANN,PHYS,14,387(1961),
24,J,RAVIER,PNR/SEPR/CA/65,010 (1965),
25,A,PAULSON,H,LISKIEN,NUKLEONIK 7,117(1965)
26,R,J,PRESTWOOD,B,P,BAYHURST,PHYS,REV,121,1438(1961),
27,H,LISKIEN,A,PAULSON,NUC,PHYS,63,393(1965),
28,J,W,MEADOWS,J,F,WHALEN,PHYS,REV,130,2022(1963),
29,J,F,BARRY,JOUR,NUC,ENER,16,467(1962),
30,N,AZZIZ,J,W,CONNELLEY,WCAP 7280(1969),

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                         ENDF/B MATERIAL NO= 1087
COPPER     AI           EVAL=SEP68 J.M.OTTER ET AL(+UKAEA EVAL.LIB.)
AI-AEC-12741(DEC.68) DIST=MAY70
*          *          *          *          *          *          *
DATA MODIFIED TO CONFORM TO ENDF/B-II FORMATS
*          *          *          *          *          *          *
COPPER     ENDF/B MAT 1087 REF. AI-AEC-12741     SEPT. 1968
MF=1                    GENERAL  INFORMATION
     ATOMIC MASS GIVEN AS 63.54   FOR A NEUTRON MASS OF 1.008665
     FOR RADIOACTIVE DECAY SEE SEPERATE ISOTOPES OF COPPER
MF=2                     RESONANCE PARAMETERS
  MT=151  CU-63
        1.ALL RESOLVED RESONANCES TREATED AS L=0 RESONANCES
        2.RESOLVED RESCNANCE PARAMETERS FROM REF.2.
        3.G VALUES FOR 7.64KEV AND ABOVE 13.5KEV ASSIGNED.
        4.NEGATIVE ENERGY RESONANCE GAMMA-N AND E0 OBTAINED FROM
          FIT TO SIGS=5.6B; SIGA=4.5B AT 2200M/S. ASSUMED GAMMA-
          GAMMA=0.55EV.
        5.L=0  UNRESOLVED RESONANCE PARAMETERS FROM AVERAGED
          RESOLVED RESCNANCE PARAMETERS. OBSERVED LEVEL SPACING
          =D0=1.1KEV, STRENGTH FUNCTION/J STATE=(S0J)=2.55E-04,
          FOR EACH J STATE D=D0/G
        6.L=1,2  S1J=S2J=1.0E-04, DJ=D0/GJ, GAMMA-GAMMA=0.55EV
          ASSUMED.
        7.OPTIONS LRU=1, LRF=2 (MLBW REF. 10) ARE USED.
          CU-65
        1.ALL RESOLVED RESONANCES TREATED AS L=0 RESONANCES
        2.RESOLVED RESCNANCE PARAMETERS FROM REF.2.
        3.G VALUES FOR 0.229KEV AND ABOVE 14KEV ASSIGNED
        4.NEGATIVE ENERGY RESONANCE GAMMA-N AND E0 OBTAINED FROM
          FIT TO SIGS=15.4B, SIGA=2.2B AT 2200M/S, ASSUMED GAMMA-
          GAMMA=0.24EV.
        5.L=0  UNRESOLVED RESONANCE PARAMETERS FROM AVERAGED
          RESOLVED RESCNANCE PARAMETERS. OBSERVED LEVEL SPACING
          =D0=1.4KEV, STRENGTH FUNCTION/J STATE=S0J=1.7E-04, FOR
          EACH J STATE D=D0/G
        6.L=1,2  S1J=S2J=1.0E-04, DJ=D0/GJ, GAMMA-GAMMA=0.24EV
          ASSUMED.
        7.OPTIONS LRU=1, LRF=2 (MLBW REF. 10) ARE USED.
MF=3                    SMOOTH CROSS SECTIONS
  MT=1    TOTAL IS EQUAL TO THE SUM OF PARTIAL CROSS SECTIONS, 30
          TO 100 KEV EXPERIMENTAL DATA OF REF.2 USED AT 130
          POINTS. ABOVE RESONANCE REGION RESULT AGREE WITH REF.5.
  MT=2    BELOW RESONANCE REGION =7.7BARNS, REF. DOC. NOTE- THE
          ABUNDANCE WEIGHTED VALUE IS 8.64BARNS.  IN
          THE RESOLVED RESONANCE RANGE THE SMOOTH DATA IS THE
          CONTRIBUTION FROM L .GT. 0 CALCULATED FROM UNRESOLVED
          RESONANCE PARAMETERS USING TRIX-REF. 4. FROM 30 TO 100
          KEV VALUES ARE THE DIFFERENCE BETWEEN THE TOTAL AND
          NON-ELASTIC CROSS SECTIONS. ABOVE 100 KEV, REF. 5.
  MT=4-13 LEVEL DATA TO 1.75 MEV. CONTINUUM ABOVE 1.75 MEV. BOTH
          FROM REF. 5.
  MT=16   REF. 5
  MT=251  MUBAR CALCULATED FROM LEGENDRE COEFFICIENTS IN FILE 4
          USING CHAD-REF. 6.
  MT=252  XI CALCULATED FROM LEGENDRE COEFFICIENTS IN FILE 4
          USING CHAD-REF. 6.
  MT=253  GAMMA CALCULATED FROM LEGENDRE COEFFICIENTS IN FILE 4
          USING CHAD-REF. 6.
  MT=102  BELOW RES. REGION CALCULATED USING UNICORN-REF. 3. FOR
          RESOLVED RES. RANGE, L .GT. 0 CONTRIBUTION CALCULATED
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ENDF/B MATERIAL NO= 1087

FROM UNRESOLVED RES. PARAMETERS USING TRIX-REF. 4. THE 30 TO 100 KEV RANGE FROM EVALUATION OF REFERENCE DOCUMENT. ABOVE 100 KEV, ABUNDANCE WEIGHTED ISOTOPIC VALUES-REF. 5. NOTE- ABUNDANCE WEIGHTED ISOTOPIC DATA ARE 45-80 PERCENT HIGHER THAN EVALUATED NATURAL CU MEASUREMENTS IN UNRESOLVED REGION.

MT=103 REF.5

MT=107 REF.5

MF=4 SECONDARY ANGULAR DISTRIBUTIONS

MT=2 LEGENDRE COEFF. FOR ELASTIC SCATT. ARE GIVEN. DATA ARE FROM REFERANCES 7,8,9. WHERE LEGENDRE COEFF. WERE NOT GIVEN THEY WERE OBTAINED FROM THE DATA POINTS BY USING CHAD-REF.6.

MF=5 SECONDARY ENERGY DISTRIBUTIONS

MT=4 REF. 5

MT=16 REF. 5

REFERENCES

1. GOLDMAN,DAVID T.,CHART OF THE NUCLIDES,KAPL(1966)
2. GOLDBERG,M.D.,ET. AL., BNL 325 2ND. ED. SUPPL. NO.2 VOL.
3. OTTER,J., NAA-SR-11980 VOL.6(1966)
4. OTTER,J.,NAA-SR-MEMO-11538 (1965)
5. OFFORD,SUSAN M.,PARKER,K.,AWRE 0-63/67 (1967)
6. BERLAND,R.F.,NAA-SR-11231 (1965)
7. GOLDBERG,M.D.,ET. AL., BNL 400 2ND ED. VOL. II (1962)
8. HOLMQVIST,B.,WIEDLING,T., NUCLEAR DATA FOR REACTORS, VOL. I,IAEA,VIENNA (1967)
9. SMITH,A.B.,ET. AL., PHY. REV. 135, B76 (1964)
10. OTTER,J.M., NSE 28, 149 (1967)

29-CU-63 1085 AI AI-AEC-12741(DEC.68) SEP68 J.M.OTTER ET.AL.(+UKNDL EVAL)

ENDF/B MATERIAL NO= 1085
CU-63 AI EVAL=SEP68 J.M.OTTER,ET AL,(+EVAL,UKAEA LIB)
AI-AEC-12741(DEC,68) DIST=MAY70 REV-MAY70
* * * * * * *
DATA MODIFIED TO CONFORM TO ENDF/B-II FORMATS
* * * * * * *
COPPER-63 ENDF/B MAT 1085 REF, AI-AEC=12741 SEPT, 1968
MF=1 GENERAL INFORMATION
ATOMIC MASS GIVEN AS 62,9296 FOR A NEUTRON MASS OF 1,008665
MT=453 RADIOACTIVE DECAY DATA FROM REF, 1
MF=2 RESONANCE PARAMETERS
MT=1511,ALL RESOLVED RESONANCES TREATED AS L=0 RESONANCES
2,RESOLVED RESONANCE PARAMETERS FROM REF,2,
3,G VALUES FOR 7,64KEV AND ABOVE 13,5KEV ASSIGNED,
4,NEGATIVE ENERGY RESONANCE GAMMA-N AND E0 OBTAINED FROM FIT TO SIGS=5,6B, SIGA=4,5B AT 2200M/S, ASSUMED GAMMA-GAMMA=0,55EV,
5,L=0 UNRESOLVED RESONANCE PARAMETERS FROM AVERAGED RESOLVED RESONANCE PARAMETERS, OBSERVED LEVEL SPACING =D0=1,1KEV, STRENGTH FUNCTION/J STATE=(S0J)=2,55E-04, FOR EACH J STATE D=D0/G
6,L=1,2 S1J=S2J=1,0E-04, DJ=D0/GJ, GAMMA-GAMMA=0,55EV ASSUMED,
7,OPTIONS LRU=1, LRF=2 (MLBW REF, 10) ARE USED,
MF=3 SMOOTH CROSS SECTIONS
MT=1 NO EXP, VALUES AVAILABLE FOR SEPERATE CU ISOTOPES, THE TOTAL WAS SET EQUAL TO SUM OF ITS PARTS,EXCEPT FOR 30 TO 100 KEV WHERE IT WAS ASSUMED TO BE EQUAL TO A SMOOTHING OF NATURAL COPPER GIVEN IN REF,2
MT=2 BELOW RESONANCE REGION VALUES WERE CALCULATED FROM RESOLVED RESONANCE PARAMETERS USING UNICORN-REF, 3, IN THE RESOLVED RESONANCE RANGE THE SMOOTH DATA IS THE CONTRIBUTION FROM L ,GT, 0 CALCULATED FROM UNRESOLVED RESONANCE PARAMETERS USING TRIX-REF,4,
FROM 30 TO 100 KEV VALUES ARE THE DIFFERENCE BETWEEN THE TOTAL AND NON-ELASTIC CROSS SECTIONS, ABOVE 100 KEV, VALUES WERE ASSUMED TO BE IDENTICAL TO NATURALLY OCCURING CU-REF,5,
MT=4-9 LEVEL DATA FROM REF,5, ABOVE 1,75MEV CONTINUUM WAS USED WHICH WAS MATCHED TO LEVEL DATA AND WHEN WEIGHTED ALONG WITH CU-65 GAVE CONTINUUM OF NATURAL CU FROM REF,5,
MT=16 REF,5
MT=251 MUBAR CALCULATED FROM LEGENDRE COEFF, IN FILE 4 USING CHAD-REF,6,
MT=252 XI CALCULATED FROM LEGENDRE COEFF, IN FILE 4 USING CHAD -REF,6,
MT=253 GAMMA CALCULATED FROM LEGENDRE COEFF, IN FILE 4 USING CHAD-REF,6,
MT=102 BELOW RESONANCE REGION CALCULATED AS PER MT=2, FOR RESOLVED RESONANCE RANGE,L,GT,0 CONTRIBUTION CALCULATED FROM UNRESOLVED RESONANCE PARAMETERS USING TRIX-REF,4, THE 30 TO 100 KEV RANGE FROM EVALUATION OF REFERENCE DOCUMENT, ABOVE 100 KEV-REF,5,
MT=103 REF,5
MT=107 REF,5
MF=4 SECONDARY ANGULAR DISTRIBUTIONS
MT=2 LEGENDRE COEFF, FOR ELASTIC SCATT, ARE GIVEN, DATA ARE AVAILABLE FOR NATURALLY OCCURING CU AND ARE ASSUMED TO BE THE SAME FOR THE SEPERATE ISOTOPES, DATA OBTAINED FROM REFERANCES 7,8,9, WHERE LEGENDRE COEFF, WERE NOT GIVEN THEY WERE OBTAINED FROM THE DATA POINTS BY USING

ENDF/B MATERIAL NO= 1085

CHAD=REF,6.

MF=5 SECONDARY ENERGY DISTRIBUTIONS

MT=4 REF, 5

MT=16 REF, 5

REFERENCES

1. GOLDMAN,DAVID T.,CHART OF THE NUCLIDES,KAPL(1966)
2. GOLDBERG.M,D.,ET. AL., BNL 325 2ND, ED, SUPPL, NO,2 VOL, IIA (1966)
3. OTTER,J., NAA=SR-11980 VOL,6(1966)
4. OTTER,J.,NAA-SR-MEMO-11538 (1965)
5. OFFORD,SUSAN M.,PARKER,K.,AWRE O-63/67 (1967)
6. BERLAND,R,F.,NAA-SR-11231 (1965)
7. GOLDBERG,M,D.,ET, AL., BNL 400 2ND ED, VOL, II (1962)
8. HOLMQVIST,B.,WIEDLING,T., NUCLEAR DATA FOR REACTORS, VOL, I,IAEA,VIENNA (1967)
9. SMITH,A,B.,ET. AL., PHY. REV, 135, B76 (1964)
10. OTTER,J,M., NSE 28, 149 (1967)

29-CU-65 1086 AI AI-AEC-12741(DEC.68) SEP68 J.M.OTTER ET.AL.(+UKNDL EVAL)

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                     ENDF/B MATERIAL NO= 1086
CU-65      AI          EVAL=SEP68 J.M.OTTER ET AL(+ UKAEA EVAL,LIB)
AI-AEC=12741(DEC,68) DIST=MAY70
*         *          *          *          *          *          *
MODIFIED TO CONFORM TO ENDF/B-II FORMATS
*         *          *          *          *          *          *
COPPER-65 ENDF/B MAT 1086 REF, AI-AEC-12741      SEPT, 1968
MF=1                     GENERAL  INFORMATION
    ATOMIC MASS GIVEN AS 64,9278 FOR A NEUTRON MASS OF 1,008665
  MT=453  RADIOACTIVE DECAY DATA FROM REF, 1
MF=2                     RESONANCE PARAMETERS
  MT=1511,ALL RESOLVED RESONANCES TREATED AS L=0 RESONANCES
        2,RESOLVED RESCNANCE PARAMETERS FROM REF,2,
        3,G VALUES FOR 0,229KEV AND ABOVE 14KEV ASSIGNED
        4,NEGATIVE ENERGY RESONANCE GAMMA-N AND E0 OBTAINED FRCM
          FIT TO SIGS=15,4B, SIGA=2,2B AT 2200M/S, ASSUMED GAMMA-
          GAMMA=0,24EV,
        5,L=0  UNRESOLVED RESONANCE PARAMETERS FROM AVERAGED
          RESOLVED RESCNANCE PARAMETERS, OBSERVED LEVEL SPACING
          =D0=1,4KEV, STRENGTH FUNCTION/J STATE=S0J=1,7E-04, FCR
          EACH J STATE D=D0/G
        6,L=1,2  S1J=S2J=1,0E-04, DJ=D0/DJ, GAMMA=GAMMA=0,24EV
          ASSUMED,
        7,OPTIONS LRU=1, LRF=2 (MLBW REF, 10) ARE USED,
MF=3                     SMOOTH CROSS SECTIONS
  MT=1      NO EXP, VALUES AVAILABLE FOR SEPERATE CU ISOTOPES, THE
            TOTAL WAS SET EQUAL TO SUM OF ITS PARTS,EXCEPT FOR 30
            TO 100 KEV WHERE IT WAS ASSUMED TO BE EQUAL TO A
            SMOOTHING OF NATURAL COPPER GIVEN IN REF,2
  MT=2      BELOW RESONANCE REGION VALUES WERE CALCULATED FROM
            RESOLVED RESCNANCE PARAMETERS USING UNICORN-REF, 3, IN
            THE RESOLVED RESONANCE RANGE THE SMOOTH DATA IS THE
            CONTRIBUTION FROM L ,GT, 0 CALCULATED FROM UNRESOLVED
            RESONANCE PARAMETERS USING TRIX-REF,4,
                          FROM 30 TO 100 KEV VALUES ARE THE
            DIFFERENCE BETWEEN THE TOTAL AND NON-ELASTIC CROSS
            SECTIONS, ABCVE 100 KEV, VALUES WERE
            ASSUMED TO BE IDENTICAL TO NATURALLY OCCURING CU-REF,5,
  MT=4-8    LEVEL DATA FROM REF,5, ABOVE 1,75MEV CONTINUUM WAS USED
            WHICH WAS MATCHED TO LEVEL DATA AND WHEN WEIGHTED ALCNG
            WITH CU-63 GAVE CONTINUUM OF NATURAL CU FROM REF,5,
  MT=16     REF,5
  MT=251    MUBAR CALCULATED FROM LEGENDRE COEFF, IN FILE 4 USING
            CHAD-REF,6,
  MT=252    XI CALCULATED FROM LEGENDRE COEFF, IN FILE 4 USING CHAD
            -REF,6,
  MT=253    GAMMA CALCULATED FROM LEGENDRE COEFF, IN FILE 4 USING
            CHAD-REF,6,
  MT=102    BELOW RESONANCE REGION CALCULATED AS PER MT=2,  FOR
            RESOLVED RESCNANCE RANGE,L,GT,0 CONTRIBUTION CALCULATED
            FROM UNRESOLVED RESONANCE PARAMETERS USING TRIX-REF,4,
            THE 30 TO 100 KEV RANGE FROM EVALUATION OF REFERENCE
            DOCUMENT, ABCVE 100 KEV-REF,5,
  MT=103    REF,5
  MT=107    REF,5
MF=4                 SECONDARY ANGULAR DISTRIBUTIONS
  MT=2      LEGENDRE COEFF, FOR ELASTIC SCATT, ARE GIVEN, DATA ARE
            AVAILABLE FOR NATURALLY OCCURING CU AND ARE ASSUMED TO
            BE THE SAME FOR THE SEPERATE ISOTOPES, DATA OBTAINED
            FROM REFERANCES 7,8,9, WHERE LEGENDRE COEFF, WERE NOT
            GIVEN THEY WERE OBTAINED FROM THE DATA POINTS BY USING
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ENDF/B MATERIAL NO= 1086

CHAD-REF,6,

MF=5 SECONCARY ENERGY DISTRIBUTIONS

MT=4 REF, 5

MT=16 REF, 5

REFERENCES

1, GOLDMAN,DAVID T.,CHART OF THE NUCLIDES,KAPL(1966)
2, GOLDBERG,M,D,,ET, AL,, BNL 325 2ND, ED, SUPPL, NO.2 VOL, IIA (1966)
3, OTTER,J,, NAA-SR-11980 VOL,6(1966)
4, OTTER,J,,NAA-SR-MEMO-11538 (1965)
5, OFFORD,SUSAN M.,PARKER,K.,AWRE O-63/67 (1967)
6, BERLAND,R,F.,NAA-SR-11231 (1965)
7, GOLDBERG,M,D,,ET, AL,, BNL 400 2ND ED, VOL, II (1962)
8, HOLMQVIST,B.,WIEDLING,T., NUCLEAR DATA FOR REACTORS, VOL, I,IAEA,VIENNA (1967)
9, SMITH,A,B,,ET, AL,, PHY. REV. 135, B76 (1964)
10, OTTER,J,M,, NSE 28, 149 (1967)

36-KR-83 1201 B+W.WADCO HEDL-TME 71-106(1971) JUL71 SCHENTER.SCHMITTROTH.LIVOLSI

These evaluations will be superceded
in ENDF/B-IV.

1. INTRODUCTION

Fifty nuclides, which represent the most important fission fragments in nuclear reactors, either thermal or fast, were selected by CSEWG. The capture data will be shown in ENDF/B3 for the following nuclides:

Krypton-83	Silver-107	Promethium-148g
Zirconium-95	Silver-109	Promethium-148m
Niobium-95	Cadmium-113	Promethium-149
Molybdenum-95	Iodine-131	Promethium-151
Molybdenum-97	Iodine-135	Samarium-147
Technetium-99	Xenon-131	Samarium-148
Ruthenium-101	Xenon-133	Samarium-150
Ruthenium-102	Cesium-133	Samarium-151
Ruthenium-103	Cesium-135	Samarium-152
Ruthenium-104	Lanthanum-139	Samarium-153
Ruthenium-105	Cerium-141	Europium-154
Ruthenium-106	Praseodymium-141	Europium-155
Rhodium-103	Praseodymium-143	Europium-156
Rhodium-105	Neodymium-143	Europium-157
Palladium-105	Neodymium-145	Gadolinium-155
Palladium-106	Neodymium-147	Gadolinium-157
Palladium-107	Promethium-147	

Five of these nuclides — Tc-99, Rh-103, Ag-107, Ag-109, and Cs-133 — were completely evaluated (LI71, BH71) separately. For the 45 remaining nuclides the main sources of data were provided by W. H. Walker (WA70) and J. L. Cook (CO71).

A computer code, FFRESCO, was written especially to handle both sets of data, to select the information on nuclides chosen by CSEWG, to perform resonance integral calculations, and to combine both sets from Walker and Cook into one ENDF/B3 set consistent with the recommendations of the Fission Products Subcommittee.

Table 2. Capture Resonance Integral Comparison

NUCLIDE	RES	ENDF/B2	WALKER	HOLDEN	COOK	D R A K E	ETOG
36KR 83	YES	2.313E+02	1.500E+02	2.250E+02	2.106E+02	1.500E+02 +OR- 50.	2.338E+02
40ZR 95	-	7.429E+00	-	2.000E+00	5.394E+00	- +OR- -	7.436E+02
41NB 95	-	2.612E+01	-	1.600E+00	2.496E+01	- +OR- -	2.616E+01
42MO 95	YES	1.066E+02	1.000E+02	1.100E+02	1.058E+02	1.100E+02 +OR- 5.	1.084E+02
42MO 97	YES	1.578E+01	1.500E+01	1.600E+01	1.498E+01	1.600E+01 +OR- 1.	1.586E+01
43TC 99	YES	1.929E+02	2.000E+02	3.060E+02	1.972E+02	1.900E+02 +OR- 20.	2.009E+02
44RU 101	YES	8.488E+01	7.600E+01	7.900E+01	8.572E+01	8.500E+01 +OR- 10.	8.577E+01
44RU 102	-	4.076E+00	4.200E+00	4.400E+00	4.117E+00	5.000E+00 +OR- 1.	4.090E+00
44RU 103	-	2.249E+00	-	2.000E+00	6.191E+01	- +OR- -	
44RU 104	-	5.428E+00	4.400E+00	4.600E+00	5.408E+00	6.000E+00 +OR- 2.	5.439E+00
44RU 105	-	5.121E+00	-	1.200E-01	5.069E+00	- +OR- -	5.151E+00
44RU 106	-	1.273E+00	2.000E+00	2.000E+00	1.277E+00	2.000E+00 +OR- .6	1.278E+00
45RH 103	YES	1.032E+03	1.100E+03	1.160E+03	1.013E+03	1.160E+03 +OR- 40.	1.032E+03
45RH 105	-	1.898E+04	1.700E+04	1.700E+04	1.696E+04	1.800E+04 +OR- 5KB	1.878E+04
46PD 105	YES	8.107E+01	8.500E+01	8.900E+01	7.449E+01	9.000E+01 +OR- 20.	8.180E+01
46PD 106	YES	8.338E+00	5.600E+00	5.700E+00	8.340E+00	1.600E+01 +OR- 5.	
46PD 107	-	7.819E+01	-	2.000E+00	8.008E+01	- +OR- -	7.833E+01
47AG 109	YES	1.430E+03	1.450E+03	1.430E+03	1.432E+03	1.460E+03 +OR- 80.	1.467E+03
48CD 113	YES	3.766E+02	-	2.050E+02	3.800E+02	3.800E+02 +OR- 20.	3.793E+02
53I 131	-	6.439E+00	8.000E+00	8.000E+00	6.279E+00	8.000E+00 +OR- 4.	6.458E+00
53I 135	-	6.765E+00	-	-	2.641E-02	- +OR- -	6.753E+00
54XE 131	YES	8.572E+02	8.300E+02	8.700E+02	7.873E+02	8.400E+02 +OR- 50.	8.860E+02
54XE 133	-	5.235E+01	-	1.600E+02	5.267E+01	1.600E+02 +OR- 20.	5.238E+01
55CS 133	YES	3.766E+02	4.500E+02	4.500E+02	3.740E+02	4.200E+02 +OR- 40.	3.826E+02
55CS 135	-	5.828E+01	5.800E+01	6.200E+01	5.805E+01	6.000E+01 +OR- 5.	5.828E+01
57LA 139	YES	1.560E+01	1.100E+01	1.200E+01	1.526E+01	1.200E+01 +OR- 1.	1.564E+01
58CE 141	-	2.909E+01	-	1.200E+01	2.869E+01	- +OR- -	2.913E+01
59PR 141	YES	1.839E+01	1.300E+01	1.800E+01	1.786E+01	1.830E+01 +OR- 1.	1.868E+01
59PR 143	-	1.565E+02	1.500E+02	1.900E+02	1.496E+02	1.900E+02 +OR- 40.	1.571E+02
60ND 143	YES	1.347E+02	6.000E+01	1.150E+02	6.452E+01	1.150E+02 +OR- 10.	1.356E+02
60ND 145	YES	2.933E+02	2.500E+02	3.000E+02	2.715E+02	2.600E+02 +OR- 15.	2.964E+02
60ND 147	-	6.450E+02	-	2.000E+01	6.441E+02	- +OR- -	6.468E+02
61PM 147	YES	2.197E+03	2.200E+03	2.200E+03	2.156E+03	2.300E+03 +OR- 400.	2.229E+03
61PM 148	-	4.497E+04	-	2.000E+04	4.395E+04	4.000E+04 +OR- 10KB	4.400E+04
61PM 149	-	8.321E+02	-	5.400E+02	9.169E+02	- +OR- -	8.389E+02
61PM 151	-	1.197E+03	-	6.000E+01	1.205E+03	- +OR- -	1.199E+03
62SM 147	YES	7.244E+02	6.000E+02	6.700E+02	5.658E+02	5.900E+02 +OR- 20.	
62SM 148	-	5.394E+01	-	2.700E+01	5.554E+01	2.000E+01 +OR- 10.	5.404E+01
62SM 150	YES	3.185E+02	2.400E+02	2.550E+02	2.400E+02	2.500E+02 +OR- 50.	
62SM 151	YES	3.047E+03	3.100E+03	3.300E+03	2.173E+03	2.450E+03 +OR- 300.	
62SM 152	YES	3.351E+03	3.000E+03	3.100E+03	2.992E+03	3.100E+03 +OR- 100.	3.458E+03
62SM 153	-	5.464E+03	-	8.000E+02	1.111E+03	- +OR- -	5.459E+03
63EU 154	-	1.321E+03	-	9.500E+02	1.250E+03	9.500E+02 +OR- 300.	1.321E+03
63EU 155	-	1.818E+03	-	1.625E+03	1.149E+03	6.000E+03 +OR- 1KB	
63EU 156	-	1.947E+03	-	8.000E+02	1.258E+03	- +OR- -	1.947E+03
63EU 157	-	1.640E+03	-	-	8.241E+02	- +OR- -	1.640E+03
64GD 155	YES	1.479E+03	-	1.630E+03	1.561E+03	1.730E+03 +OR- 200.	1.505E+03
64GD 157	YES	8.351E+02	-	7.000E+02	1.315E+03	7.900E+02 +OR- 50.	8.407E+02
61PM 148	-	3.103E+04	-	5.500E+03	3.197E+04	3.000E+04 +OR- 10KB	3.103E+04

2. DATA PROCESSING PROCEDURE

Walker has recommended the resolved resonance parameters for approximately 130 fission fragment nuclides. Cook has included in the Australian file, similar to ENDF, data for about 190 nuclides. None, however, have explicit resonance parameters. Furthermore, below 5 keV Cook's data are represented by a histogram. It is undoubtedly an average cross section taken over the possible range of resonances.

The 2200 m capture cross section values for the 50 recommended nuclides were worked out for the Fission Product Subcommittee (FPS) by the Standards Subcommittee (STD) of CSEWG.

The following procedure was used in combining the three sets of data:

1. All nuclides in the Walker, Cook, and FPS sets were analyzed.
2. Only the FPS nuclides were prepared for ENDF/B3.
3. For all nuclides, whether or not they had explicit resonance parameters, the effective scattering radius was calculated, and for those nuclides with resonances the upper limit EH of the resonance range was determined, the lower limit being 10^{-2} meV.
4. While all the FPS requested nuclides could be found in Cook's file, not all of them may have resonance parameters; therefore:
   a. If a requested nuclide does not have explicit resonance parameters, the cross section of 2200 m given by Cook is compared with the one recommended by STD. The difference between these two values is assumed as a 1/v-type correction and is applied to the entire energy range.
   b. If the requested nuclide has explicit resonance parameters, the cross sections at 2200 m from the resonance

tails and from Cook are compared with the one recommended by STD. Two 1/v-type components are then obtained — one for the resonance energy range (10^{-5} eV up to EH) and the other to affect Cook's cross sections (from EH + ε up to 15 MeV).

5. Reduced resonance integrals were calculated for nuclides with resonance parameters. Total and partial (from EH + ε to 15 MeV) capture integrals were calculated from Cook's smooth data. Any 1/v-type correction effect on the integrals was also taken into consideration.

6. Finally, tabulations of the cross sections at 2200 m with components to the resonance integrals and a comparison of the latter with values given by several evaluators were compiled automatically.

3. RESULTS

3.1. Thermal Cross Section

All the nuclides, Walker's and Cook's, whose data were analyzed are reported in Table 1. The nuclides requested by FPS are indicated by an asterisk, and the last nuclide is Pm-148m. The 2200 m value of the cross section is reported in Table 1. For those nuclides which have resonance parameters, the 1/v CORR column reports the difference between the STD recommended value and the one obtained from the resonance tails. For those nuclides without resonance parameters, the same column reports the difference between STD and Cook's values.

3.2. Resonance Integrals

The contributions to the resonance integral, the capture integral calculated from Cook's data, and, finally, the total integral for the requested nuclides are also listed in Table 1.

Table 2 shows a comparison of resonance integrals as computed for the set of nuclides requested by FPS with the values estimated by Walker, Holden, and Drake (WA70, DR71). It must be mentioned that Walker's values are for the reduced resonance integral. In the majority of cases this would make little difference, but it does account for the large discrepancy of Nd-143 and a few other nuclides.

The third and last columns of Table 2 report the resonance integral values calculated by FFRESCO and ETOG. These values are very close for any given nuclide, and the difference may be found in the different calculational techniques used by the two codes. For example, while ETOG computes the resonance integral by integrating point resonance cross sections on a more or less tight energy mesh, FFRESCO calculates the integral of each peak according to

$$I_\infty = 2\,\frac{\pi^2}{k^2}\,g_J \times \frac{\Gamma_n \Gamma_\gamma}{\Gamma_T} \times \frac{1}{E_r}\,,$$

provided that $E_r >> \Gamma_T$. If this condition is not satisfied, the integral is calculated from point cross sections obtained through DR70:

$$\sigma(E) = \frac{\pi}{k^2} g_J \sum_i \frac{\Gamma_{ni}\Gamma_{\gamma i}}{(E - E_{ri})^2 + \frac{1}{4}\Gamma_{ri}^2}$$

summed over all resonances for which $E_r \sim \Gamma_T$, and the total number of points distributed between $E_{ri} - 5\Gamma_{ri}$ and $E_{ri} + 5\Gamma_{ri}$ is no less than 400.

Different interpolating techniques also account for some slight differences in the total integration.

3.3. High Energy Cross Sections

In order to have a more direct way to compare Cook's high energy cross section, the 30-keV energy point was selected since it is one of the most recurrent points in experiment reports listed in BNL-325. Table 3 reports Cook's capture cross section at 30 keV and also the capture integral over a fission spectrum (Pu-239, ENDF/B2), since similar integral data are becoming more frequent (SC71).

Not all 192 nuclides in Cook's file have experimental reports for the 30-keV cross section. However, the agreement between Cook's values and the one reported in BNL-325 is very good for Mo-95, -96, -97, -100; Sn-115, -117, -118, -119, -120; Te-124, -125, -126, -128, -130; I-127; Pr-141; Sm-147, -148, -149, -150, -152; and Tb-159. Close agreement was also reported for Ru-103, -104, Cd-114, Sn-124, Ba-138, Ce-142, and Sm-154.

Somewhat puzzling are the 30-keV capture cross sections for Pd-110 and Sn-122. However, no complete search of the SCISRS file was made to ascertain the direction that ENDF/B should follow since neither nuclide was requested by FPS.

Since Benzi and Reffo (BE69) have worked on the fission fragment capture cross section from 1 keV to 10 MeV, it was thought worthwhile to make a spot comparison of Cook's and Benzi's sets at 30 keV. Not all nuclides common to both sets have been compared. The agreement is excellent for As-75, Kr-82, Mo-97, Ru-102, Ru-104, I-127, Xe-131, La-139, Nd-143, Sm-48, and Sm-150.

Cook's values are lower than Benzi's for Ge-72, -73, -74, -76; Se-76, -77, -78; Kr-83; Pd-105, -106; Cd-113, -114; Pr-141; Sm-147, -152; Gd-155, and Gd-157. The situation is reversed for Se-80, Br-81, Kr-84, Zr-95, Mo-95, and Ru-101.

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SUMMARY DOCUMENTATION OF TWENTY-SEVEN FISSION PRODUCT ISOTOPES FOR ENDF/B-III, MAT 1201-1231*

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I. INTRODUCTION

This summary describes the cross section evaluation of 27 (MAT 1201-1231) of 55 fission product isotopes selected by the Fission Product Subcommittee of the Cross Section Evaluation Working Group (CSEWG) for inclusion in ENDF/B-III. The 55 isotopes were selected because they were determined to be most important for fast and thermal reactor analyses. The authors of this report were assigned responsibilities for the evaluation of isotopes with an atomic mass number less than 142, which generally constitute nuclei of non-deformation. Not included are the following isotopes which have been previously evaluated by other groups: Tc-99, Rh-103, Ag-109, Cs-133, and Xe-135 (MAT 1209, 1216, 1222, 1228, 1026).

Theoretical calculations of the radiative capture cross section of all 27 isotopes were made using the Hauser-Feshbach (with width fluctuation correction) formalism. These results were incorporated in the evaluations for the "fast neutron" energy region (E > EH, EH = Maximum of 1 KeV or upper energy of the resolved resonance region).

Radiative capture cross sections for the thermal and the resolved resonance energy regions and radioactive decay data were obtained from the evaluations of Livolsi[2].

Elastic scattering and inelastic scattering cross section values were obtained from the work of Cook.[3]

The form of this summary follows the ENDF/B data tape structure (File 1, File 2, and File 3).[4] A description of the methods and results which go into producing File 3 ("smooth cross section" data) is included.

*This summary is a condensed version of the report in Reference 1.

II. FILE 1: GENERAL INFORMATION

Atomic masses of individual isotopes were obtained from the "Chart of the Nuclides"[5] and the "Table of Isotopes"[6].

Radioactive decay data (MT = 453) was put into the ENDF/B format by Livolsi[2]. The "Table of Isotopes"[6] and works by Cenacchi[7] and Mattauch et al[8] were used for decay constants, chains and Q-values of target and compound nuclei.

Additional information (MT = 451) was also taken from Livolsi[2] relating to 2200 M/S capture cross sections and capture resonance integrals as calculated from the File 2 and File 3 data.

III. FILE 2: RESONANCE PARAMETERS

All File 2 information was put into the ENDF/B format by Livolsi[2]. Resolved resonance parameters from Walker[9] are given. All resonances are prescribed to be s-waves. When no resolved resonance energy region is specified (LRP = 0) the effective scattering radius is included, consistent with ENDF/B format specifications[4].

IV. FILE 3: SMOOTH CROSS SECTIONS

The energy points are the same for all reaction types. They were obtained by combining the energy mesh of Livolsi[2], Cook[3], and the theoretical calculations described in the radiative-capture section. The log-log interpolation scheme (INT=5) is prescribed for all reaction types.

A. Total Cross Sections (MT=1)

Total cross sections were obtained by adding elastic scattering, inelastic and radiative capture cross sections at all energies (1.0×10^{-5} ev to 15 Mev).

B. Elastic Scattering Cross Sections (MT=2)

Elastic scattering cross section values were obtained from the work of Cook[3]. For energy points intermediate to Cook's, a log-log interpolation was made to get the cross section.

C. Inelastic Scattering Cross Sections (MT=4)

Inelastic scattering cross section values were obtained from the work of Cook[3]. For energy points intermediate to Cook's, a log-log interpolation was made to get the cross section.

D. Radiative Capture Cross Sections (MT=102)

Evaluation of the radiative capture cross section ($\sigma(n,\gamma)$) was divided into two energy regions E < EH and E > EH. The boundary energy EH was determined to be the maximum of 1 KeV or EHF2 (the upper energy limit of the resolved resonance region).

1. E < EH

Livolsi's[2] evaluation was mainly used here. In general, the cross section which is added to the resonance parameter results, is constructed to give correct 2200 M/S and resonance integral values. For the case EH > EHF2, Cook's[3] results were used for energies greater than EHF2.

2. E > EH - Theoretical Model

For this energy region the cross section is completely given by the File 3 values. It is also given in terms of an average cross section. The ultrafine energy structure for the resolved resonance region is no longer provided. This average cross section was obtained using a theoretical model, the well known

Hauser-Feshbach[10] (with width fluctuation correction) formalism. In addition for high energies ($E \gtrsim 1$ Mev) the direct capture cross section contribution was included. A detailed report on the use of this model for the calculation of the capture cross section of fission product isotopes including comparisons with experimental data has been published by one of the authors (FAS)[11].

3. E > EH - Results

The averaged radiative capture cross section $\sigma_{n\gamma}$ was calculated using Eq. (1) for several incident neutron energies. The calculations were made with the computer code NCAP*. Results of these calculations for all 27 fission product isotopes are given in Figures 5-31.**

In Figures 5-31 the results called "EVALUATION CASE 101"† are plotted along with the evaluations of Cook[3] and Benzi[13] and, when available, experimental data obtained from the CSISRS library††.

The following information, together with the above equations, essentially specifies these cross section calculations:

1. Neutron transmission coefficients T_c were calculated using the Moldauer[14] optical model potential, except that the spin-orbit term was set equal to zero.
2. Level spacing input parameters used for each isotope are given in Table 2. The level density parameters a and pairing energies P were computed from tables given by Cook and Musgrove[15]. Except for the following cases, the level-density parameters a were readjusted to give recent D_{obs} values given by Musgrove[16]: Values for Mo-95, Mo-97, and Mo-98 were obtained from Shwe and Coté[17]. For Pd-105, D_{obs} was obtained from

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* The computer code NCAP was written to do radiative capture cross section calculations. A complete description of the equations used by this code are given in Reference 11.

† Case numbers identify particular sets of results for a given isotope and are only significant to the authors of this report.

†† An automated Cross Section Information Storage and Retrieval System (CSISRS) is maintained and made available from the National Neutron Cross Section Center (NNCSC at Brookhaven National Laboratory.

** The figures were obtained from Reference 1.

BNL-325,[18] and for La-139 D_{obs} was adjusted to fit the neutron capture data. D_{obs}, the mean s-wave level spacing, is related to the level-density parameter a through the following expression:

$$1/D_{obs} = \left[(I + 1)e^{-(I + 1)^2/2\sigma^2} + Ie^{-I^2/2\sigma^2}\right]\rho_o(B_N). \quad (16)$$

3. Radiation widths at binding energy excitation $\Gamma_\gamma(B_n)$ called GG in Table 2 were obtained in several ways. Experimental values were obtained from BNL-325[18] and from work by Shwe and Coté[17] and by Julien et al[19] where available. If experimental values for Γ_γ were unknown, values were obtained by interpolation from known values of neighboring isotopes. In addition, for some cases with experimental neutron-capture data, the theoretical cross sections were made to agree with the data by varying Γ_γ as for Mo-95, Mo-97, Mo-98, and Mo-100.

4. The constant C in Eq. (15) was adjusted to fit radiative-capture data at 14.5 MeV. Its value was found to be 1.0 x 10^{-6} barns $-(MeV)^{-3/2}$

5. The cross section for Mo-98 was taken to be .5 times the value calculated from the parameters given in Table 2. This adjustment was made to give a cross section more consistent with experimental data points and also a measured integral result from the C F R M F[20].

6. The sum of the isotopic cross sections for molybdenum, rubidium, and palladium were compared to the experimental cross sections for the naturally occurring elements. Calculations by Benzi and by Musgrove were used for naturally occurring isotopes which are not included in this work. In each case, however, the isotopes in this work were the main contributors to the cross sections for the naturally occurring elements. The computed cross sections for natural Mo, Ru, and Pd are .167, .156, and 3.78 barns respectively.

These numbers compare, respectively, to experimental values of .160, .170, and .440 barns. The maximum discrepancy is only 14% for Pd. The molybdenum and palladium cross sections were compared at 30 KeV while an incident neutron energy of 195 KeV was used for rubidium.

TABLE 2. INPUT PARAMETERS FOR CAPTURE CALCULATIONS

GG = RADIATION WIDTH (MV)
DOBS = S-WAVE LEVEL SPACING (EV)
BN = NEUTRON BINDING ENERGY (MEV)

A = LEVEL DENSITY PARAMETER
P = PAIRING ENERGY

TARGET NUCLEUS	GG	DOBS	BN	TARGET NUCLEUS		COMPOUND NUCLEUS	
				A	P	A	P
36 KR 83	220.	.545+02	10.5193	12.07	1.01	11.69	2.63
40 ZR 95	200.	.418+03	7.8381	12.91	1.22	13.25	2.61
41 NB 95	200.	.111+03	6.9313	11.90	1.68	12.82	.39
42 MO 95	350.	.127+03	9.1567	11.90	.67	12.64	2.59
42 MO 97	220.	.665+02	8.6422	12.91	1.30	14.48	2.89
42 MO 98	100.	.275+03	5.9187	14.46	2.69	16.53	.52
42 MO 99	260.	.127+03	8.2997	16.53	.52	14.56	1.97
42 MO 100	150.	.120+04	5.3901	14.55	1.97	16.81	1.09
44 RU 101	192.	.140+02	9.2161	14.65	.50	14.90	1.95
44 RU 102	290.	.264+03	6.2475	14.90	1.95	17.31	1.07
44 RU 103	170.	.230+02	8.8873	17.31	1.07	15.75	2.44
44 RU 104	160.	.784+03	5.9765	15.75	2.44	14.89	.68
44 RU 105	155.	.233+02	8.4044	14.89	.68	16.78	2.40
44 TO 106	145.	.130+04	5.5434	16.78	2.40	15.39	.71
45 RH 105	155.	.184+02	6.5724	16.09	1.21	14.89	-.55
46 PD 105	153.	.880+01	9.5474	15.24	1.27	16.41	2.64
46 PD 106	145.	.463+03	6.5323	16.41	2.64	15.05	.89
46 PD 107	140.	.104+02	9.2275	15.05	.88	16.77	2.60
46 PD 109	130.	.609+02	8.8074	17.83	.91	15.39	2.92
48 CD 113	110.	.227+02	9.0479	17.82	1.13	17.77	2.75
53 I 131	115.	.723+02	6.3448	13.97	.92	13.50	-.35
53 I 135	90.	.120+05	3.6814	8.64	1.05	18.37	-.25
54 XE 131	110.	.250+02	8.9323	16.61	.73	15.29	1.92
54 XE 133	110.	.410+03	8.4599	14.26	.65	12.29	2.19
55 CS 135	105.	.328+03	6.6114	12.83	1.28	11.57	.09
55 CS 137	95.	.193+04	4.3114	10.81	1.14	12.55	-.08
57 LA 139	55.	.262-03	5.0004	13.34	1.25	14.84	-.05

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15. J. L. Cook, H. Ferguson, and A. R. del Musgrove, "Nuclear Level Densities in Intermediate and Heavy Nuclei", Aust. J. Phys. 20 (1967) 477.

41-NB-93 1164 GGA GA-8133+ADD (67) JAN67 ALLEN.DRAKE.MATHEWS (MOD SEP 71)

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                       ENDF/B MATERIAL NO= 1164
NIOBIUM   GGA             EVAL=JAN67 M.S.ALLAN AND M.K.DRAKE
GA-8133 (1967)            DIST=JUL68 REV-SEPT71
*          *          *          *          *          *          *
DATA REVISED JUNE,1970 TO CONFORM TO ENDF/B DATA FORMATS
*          *          *          *          *          *          *
NIOBIUM    ALLEN*DRAKE (GGA)        GA-8133(1967)+ADDEND JUNE 1969
DATA CORRECTED JUNE 1969
THIS DATA SET IS A REVISED VERSION OF MAT=1024
THE REVISONS ARE DESCRIBED IN REPORT  GA-8133(ADDENDUM),1969
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
NIOBIUM NEUTRON CROSS SECTIONS
JANUARY 1967
DATA TAKEN FROM EVALUATION BY ALLEN AND DRAKE (GA-8133) AND
E.L. SLAGGIE (KAPL NEWSLETTER 6-65, MARCH 25, 1965)

MF= 2 MT=151       RESOLVED RESONANCE PARAMETERS TAKEN FROM
                   RECOMMENDED DATA GIVEN IN BNL-325, SUPPL NO 2
                   VOL IIB (MAY 1966)
                   UNRESOLVED RESONANCE PARAMETERS FOR S-WAVE
                   NEUTRONS TAKEN FROM GARG, ET AL, PHYS, REV,
                   137, B547(1965)
MF= 3 MT=  1       UP TO 7.5 KEV, USE RESONANCE PARAMETERS
                   ABOVE 7.5 KEV, DATA FROM BNL-325
MF= 3 MT=  2       UP TO 7.5 KEV, USE RESONANCE PARAMETERS
                   ABOVE 7.5 MEV, ELASTIC= TOTAL MINUS NON-ELASTIC
                   S-WAVE PART GIVEN BY UNRESOLVED PARAMETERS FOR
                   7.5 KEV TO 0.5 MEV
MF= 3 MT=  4       INELASTIC SCATTERING  0.03 TO 2.5 MEV FROM SUM
                   OF LEVELS(FROM EXPERIMENTAL DATA AND OPTICAL
                   MODEL CALCULATIONS),ABOVE 2.5 MEV OBTAINED
                   BY SUBTRACTING OTHER CROSS SECTIONS FROM
                   NONELASTIC CROSS SECTIONS
MF= 3 MT=  16      CURVE THROUGH DATA IN BNL-325
MF= 3 MT=  102     (N-GAMMA) 0.001EV  TO  7.5 KEV RESOLVED
                    RESONANCE PARAMETER, 1/V PART ADDED TO GIVE
              1.15 BARNS AT 0.0253EV.  7.5KEV TO   0.5 MEV DATA
              GIVEN AS DIFFERENCE BETWEEN TOTAL (N-GAMMA) AND
              S-WAVE PART FROM UNRESOLVED PARAMETERS TOTAL
              (N-GAMMA) 7.5 KEV TO 15MEV, CURVE DRAWN THROUGH
              DATA GIVEN IN BNL-325 PLUS RECENT DATA BY KOMPE;
              (KFK 455 ,1966)
MF=3 MT=251,252,253 CALCULATED BY CHAD
MF= 4 MT= 2        DIFF ELASTIC  COEF FROM OPTICAL MODEL CODE
MF= 5 MT= 4        DATA GIVEN FOR ELEVEN LEVELS FOR ENERGIES
                   UP TO  2.5 MEV. NUCLEAR TEMPERATURE FROM
                   THOMSON (PHYS, REV,,129,1649(1963) GIVEN FOR
                   ENERGIES ABOVE 2.5MEV.
** * * * * * * * * * * * * * * GGA CHANGES JUNE 1969  * * * * * * *0
FILE 2
CORRECT UNRESOLVED RESONANCE PARAMETERS  REF. GA 8133 ADDENDUM
FILE 3
CORRECT N,GAMMA  CROSS SECTION FROM .001 EV TO 7.5 KEV
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * **
* * * * * * * * * * * * *GGA CHANGES SEPT 1971* * * * * * * * * * **


MF=3,MT=4

              TOTAL INELASTIC CROSS SECTION BELOW 1.5MEV REDUCED
              BECAUSE OF DATA OF REF. 1 AND RE-EVALUATION OF OLDER
              DATA, SMOOTH CURVE DRAWN FROM 1.5MEV THROUGH 6 AND
```

ENDF/B MATERIAL NO= 1164

7.5MEV DATA OF REF. 2. INELASTIC CROSS SECTION REDUCED ABOVE N,2N THRESHOLD TO PRESERVE NON-ELASTIC CROSS SECTION.

MF=3,MT=16

THE ARGUMENT OF REF. 3 WAS ACCEPTED RESULTING IN A 2.5 TIMES INCREASE IN THE N,2N CROSS SECTION (AT THE EXPENSE OF INELASTIC).

MF=3,MT=51-59

INDIVIDUAL LEVELS BASED ON DATA OF REF. 1 WITH SUM OF LEVELS NORMALIZED TO THE EVALUATED TOTAL INELASTIC. LEVEL DATA TERMINATED AT 1.4MEV DUE TO INADEQUATE LEVEL DATA AND RAPIDLY INCREASING LEVEL DENSITY.

MF=3,MT=91

CONTINUUM IS TOTAL INELASTIC ABOVE 1.4MEV.

MF=5,MT=91

NUCLEAR TEMPERATURE BASED ON DATA OF REF. 2.

REFERENCES*

1. ROGERS, ET AL, NSE 45,297(1971)
2. HOPKINS AND DRAKE, NSE 36, 275(1969)
3. BLOW, AERE-R 6540 (1971)

* *

42-MO 1111 ANL ANL-7387 (1968) OCT66 E.PENNINGTON (MOD. OCT 69)

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                  ENDF/B MATERIAL NO= 1111
MO        ANL          EVAL-OCT66 E.PENNINGTON (NATURAL ELEMENT)
ANL-7387 (1968)        DIST-JUL68 REV-JAN72
         MOLYBDENUM  *****     DATA REVISED FROM MAT=1025
*        *         *         *         *         *         *
DATA MODIFIED JAN,1972
THE LOW ENERGY RADIATIVE CAPTURE CROSS SECTION WAS CHANGED TO
CONFORM TO THE CSEWG NORMALIZATION AND STANDARDS SUBCOMMITTEE
RECOMMENDED VALUE OF 2.65 BARNS FOR THE 2200 M/SEC  X/S
*        *         *         *         *         *         *
THE ORIGINAL VERSION WAS PREPARED IN OCTOBER 1966,
THE DATA WERE REVISED IN OCTOBER 1969.
THE MOST SIGNIFICANT REVISIONS ARE A LARGE DECREASE IN THE
(N,GAMMA) CROSS SECTION IN THE RANGE FROM 1 TO 20 KEV,, AND THE
INCLUSION OF UNRESOLVED RESONANCE PARAMETERS IN THE RANGE FROM 1
TO 100 KEV, THE ORIGINAL VERSION LED TO HIGH VALUES OF CALCULATED
CENTRAL WORTHS FOR FAST ASSEMBLIES BECAUSE OF THE LARGE (N,GAMMA)
CROSS SECTION,
A DESCRIPTION OF THE COMPILATION OF THE ORIGINAL VERSION IS GIVEN
IN REF.1.
AN OUTLINE OF THE DATA SOURCES IS GIVEN BELOW,
MF=2 MT=151               RESONANCE PARAMETERS
 RESOLVED PARAMETERS FOR 46 RESONANCES IN 7 ISOTOPES COVER THE
 RANGE FROM 4 EV. TO 1 KEV.,WHILE UNRESOLVED PARAMETERS COVER THE
 RANGE FROM 1 TO 100 KEV, DATA FROM REF.2-11 WERE CONSIDERED IN
 DETERMINING THE RESOLVED PARAMETERS, THE UNRESOLVED PARAMETERS
 ARE BASED ON REF,12,
MF=3                              SMOOTH DATA
 MT=1 THE TOTAL CROSS SECTION WAS OBTAINED BY SUMMING THE PARTIAL
 CROSS SECTIONS,
 MT=2 THE ELASTIC SCATTERING CROSS SECTION IS A CONSTANT 5 BARNS
 BELOW 4 EV, IN THE RESOLVED RESONANCE RANGE,A SMOOTH BACKGROUND
 RANGING FROM 0.65 BARNS AT 4 EV, TO 0.75 BARNS AT 1 KEV, IS TO
 BE ADDED TO SCATTERING CALCULATED FROM RESONANCE PARAMETERS, NO
 SMOOTH BACKGROUND IS GIVEN IN THE UNRESOLVED RANGE, ABOVE 100
 KEV.,THE VALUES OF THE ORIGINAL COMPILATION (REF,1) ARE USED,
 MT=4 THE INELASTIC SCATTERING CROSS SECTION OF REF,1 IS USED,
 FROM 200 KEV,TO 1.5 MEV.,THIS CONSISTS OF THE SUM OF THE CROSS
 SECTIONS FOR THE EXCITATION OF 4 LEVELS AS DETERMINED IN REF,13.
 THE VALUE AT 1.5 MEV, IS JOINED SMOOTHLY TO THE 2 MEV, VALUE OF
 REF,14. FROM 2 TO 10 MEV.,THE VALUES OF REF.14 ARE USED EXCEPT
 (N,2N) AND (N,3N) CROSS SECTIONS ARE SUBTRACTED ABOVE THEIR
 THRESHOLDS, ABOVE 10 MEV.,THE REACTION CROSS SECTION WAS ASSUMED
 CONSTANT, AND (N,2N),(N,3N),AND THE ORIGINAL (N,GAMMA) CROSS
 SECTIONS WERE SUBTRACTED TO YIELD THE INELASTIC CROSS SECTION,
 MT=16 THE (N,2N) CROSS SECTION WAS CALCULATED BY S,PEARLSTEIN,
 SEE REF,15,
 MT=17 THE (N,3N) CROSS SECTION WAS CALCULATED BY S,PEARLSTEIN,
 SEE REF,15.
 MT=102 THE (N,GAMMA) CROSS SECTION IS TAKEN AS 1/V UP TO ABOUT
 10 EV. CORRESPONDING TO A VALUE OF 2.7 BARNS AT 0.0253 EV. FROM
 4 EV. TO 10 EV.,ONLY THE BACKGROUND TO BE ADDED TO THE CROSS
 SECTION CALCULATED FROM RESONANCE PARAMETERS IS PROVIDED, THEN
 NO SMOOTH BACKGROUND IS GIVEN UNTIL OVER 900 EV.,WHERE A BACK-
 GROUND IS SUPPLIED SO THAT THE CROSS SECTION CALCULATED FROM
 RESOLVED PARAMETERS JOINS SMOOTHLY AT 1 KEV, TO THAT CALCULATED
 FROM UNRESOLVED PARAMETERS PLUS BACKGROUND, FROM 1 TO 100 KEV.,
```

A BACKGROUND, WHICH IS NEGATIVE OVER ALMOST THE ENTIRE RANGE, IS PROVIDED SO THAT THE UNRESOLVED RESONANCE PLUS BACKGROUND CROSS SECTIONS ADD TO THOSE NOW RECOMMENDED. THE NEW RECOMMENDED CROSS SECTIONS IN THIS 1-100 KEV. RANGE ARE BASED ON A LARGE SELECTION OF EXPERIMENTAL DATA SUMMARIZED IN REF.11,16,17,AND EVALUATED CURVES BY SCHMIDT (REF.11,18),AND POENITZ (REF.16). FROM 100 KEV.TO 1 MEV., THE (N,GAMMA) CROSS SECTION IS FROM REF.16,EXCEPT FOR BEING RAISED SLIGHTLY NEAR 1 MEV. TO JOIN SMOOTHLY WITH THE VALUES OF SCHMIDT (REF.11,18), WHICH ARE USED FROM 1 TO 10 MEV. THE EXTENSION FROM 10 TO 15 MEV. IS MADE BY ASSUMING A 1/E VARIATION.

MT=251,252,253 THE VALUES OF MU BAR LAB, XI, AND GAMMA WERE CALCULATED USING MODIFIED VERSIONS OF SUBROUTINES FROM THE CHAD CODE.(REF.19,1).

MF=4 MT=2 ELASTIC ANGULAR DISTRIBUTIONS

ELASTIC SCATTERING LEGENDRE COEFFICIENTS IN THE CENTER-OF-MASS SYSTEM WERE OBTAINED FROM H.ALTER (REF.20) UP TO 6 MEV. ABOVE 6 MEV.,THE LEGENDRE COEFFICIENTS WERE BASED ON ABACUS OPTICAL MODEL CALCULATIONS. A CENTER-OF-MASS TO LABORATORY TRANSFORMATION MATRIX WAS CALCULATED USING CHAD.(REF.19).

MF=5 SECONDARY ENERGY DISTRIBUTIONS

MT=4 PROBABILITIES FOR EXCITING THE 4 RESOLVED LEVELS (REF.13) ARE TABULATED. NUCLEAR TEMPERATURES FOR LAW LF=9 ARE CALCULATED AS IN REF.21.

MT=16,17 NUCLEAR TEMPERATURES FOR LF=9 LAWS FOR (N,2N) AND (N,3N) REACTIONS ARE CALCULATED AS DESCRIBED IN REF.1.

MF=7 MT=4 THERMAL SCATTERING LAW

PARAMETERS FOR A FREE GAS THERMAL SCATTERING LAW ARE INCLUDED.

REFERENCES

1. E.M.PENNINGTON AND J.C.GAJNIAK,ANL-7387(1968).
2. M.I.PEVZNER ET AL,SOVIET PHYSICS JETP,17,803(1963).
3. H.SHWE AND R.E.COTE,PHYSICAL REVIEW,179,1148(1969).
4. S.WYNCHANK ET AL,PHYSICAL REVIEW,166,1234(1968).
5. H.WEIGMANN AND H.SCHMID,NUCLEAR PHYSICS,A104,513(1967).
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8. J.J.SCHMIDT,KFK 718,PARTB(1968).
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10. S.F.MUGHABGHAB ET AL,B.A.P.S.,12,1199(1967).
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13. A.B.SMITH AND R.HAYES,NUCLEAR PHYSICS,A93,609(1967).
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16. W.POENITZ,(A.N.L.),PRIVATE COMMUNICATION,(1969).
17. M.DRAKE,(B.N.L.),PRIVATE COMMUNICATION,(1969).
18. I.LANGNER,J.J.SCHMIDT,D.WOLL,KFK 750,(1968).
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20. H.ALTER,PRIVATE COMMUNICATION,SEE ALSO NAA-SR-11980,VOL.4,1967
21. S.YIFTAH ET AL,FAST REACTOR CROSS SECTIONS,PERGAMON,1960,P.49.

43-TC-99 1137 B+W BAW-1367 OCT71 Z.LIVOLSI

ENDF/B MATERIAL NO= 1137

TECHNETIUM-99 EVALUATED BY ZIZO LIVOLSI BABCOCK+WILCOX OCTOBER 71

SIGMA-TOTAL 2200M/SEC= 24.07 B
SIGMA-SCAT. 2200M/SEC= 5.04 B
SIGMA-CAPT. 2200M/SEC= 19.03 B
1/E WEIGHTED CAPT.INTEGRAL ABOVE .5EV= 353.35 B

FOR ALL PERTINENT INFORMATION REGARDING THESE DATA, PLEASE REFER TO BAW-1367 (OR ENDF-144)

FILE CONTENTS
1-453 DECAY CHAIN (1,2,3)
2-151 RESOLVED RESONANCES AND BOUND LEVEL (4) ALL S-WAVE
      UNRESOLVED RESONANCES (5) S AND P-WAVES
3-001 TOTAL CROSS SECTION CALCULATED BY OPTICAL MODEL (6) CONVER-
      GING ON EXPERIMENT (7) ABOVE 2.MEV
3-002 ELASTIC SCATTERING XSECTION RESULTANT OF COMPOUND (8) AND
      SHAPE ELASTIC (6)
3-004 TOTAL (N,N*) SCATTERING (8)
3-016 (N,2N) SCATTERING (9,10)
3-051 EXCITED DISCRETE (N,N*) LEVELS (1,8)
 THRU EXCITED DISCRETE (N,N*) LEVELS (1,8)
3-061 EXCITED DISCRETE (N,N*) LEVELS (1,8)
3-091 (N,N*) LEVELS DESCRIBED BY CONTINUUM (8)
3-102 CAPTURE XSECTION BELOW 300EV DUE TO RESOLVED RESONANCES(4)
      UP TO 140KEV CORRECTION IMPOSED ON UNRESOLVED XSECTION(5)
      UP TO 15MEV IN COMPETITION WITH EXCITED LEVELS AND CORRECTD
      FOR ENERGY VARIATION OF GAMMA STRENGTH FUNCTION (8,11) AB-
      OVE 5MEV CONTRIBUTION FROM DIRECT + COLLECTIVE CAPTURE (12)
4-002 DIFF. ELASTIC CALCULATED BY MR BHAT FOR AG (NO EXP DATA)
5-016 MAXWELLIAN EVAPORATION SPECTRUM FOR (N,2N)
5-091 MAXWELLIAN EVAPORATION SPECTRUM FOR (N,N*)

REFERENCES
1- CM LEDERER, JM HOLLANDER, I PERLMAN, 6TH ED(1967)
2- G CENACCHI, T/FIMA(68)4
3- THE MATTAUCH, W THIELE, AH WAPSTRA, NUCL.PHYS 67(1965)
4- T WATANABE,SD REEDER, NSE 41,188(1970)
5- JEN-CHANG CHOU, INR-4/70-28 (N/1970)
6- ABACUS- EH AUERBACH, BNL-6562 (1964)
7- W FOSTER, SCISRS FILE (BNW-1967)
8- COMNUC- CL DUNFORD, AI-AEC-12931
9- S PEARLSTEIN, NUCL.DATA 3A,327(1967)
10- JM BLATT, VF WEISSKOPF, THEOR.NUCL.PHYSICS, P.484
11- GGOD- AZ LIVOLSI, A PRINCE (NOT RELEASED)
12- FISPRO2- V BENZI, GC PANINI, G REFFO, CEC(69)24

45-RH-103 1125 B+W BAW-1367 OCT71 Z.LIVOLSI

ENDF/B MATERIAL NO= 1125

RHODIUM - 103 EVALUATED BY ZIZO LIVOLSI BABCOCK+WILCOX OCTOBER 71

SIGMA-TOTAL 2200M/SEC= 151,68 B
SIGMA-SCAT, 2200M/SEC= 3,46 B
SIGMA-CAPT, 2200M/SEC= 148,21 B
1/E WEIGHTED CAPT,INTEGRAL ABOVE ,5EV=1048,34 B

FOR ALL PERTINENT INFORMATION REGARDING THESE DATA, PLEASE REFER TO BAW=1367 (OR ENDF-144)

FILE CONTENTS
1-453 DECAY CHAIN (1,2,3)
2-151 RESOLVED RESONANCES (4,5) S ET P-WAVES
UNRESOLVED RESONANCES (4) S ET P-WAVES, OBS,LVL,SPAC,(5)
3-001 TOTAL CROSS SECTION CALCULATED BY OPTICAL MODEL (6) CONVER-GING ON EXPERIMENT BELOW (7) AND ABOVE (8) 2MEV
3-002 ELASTIC SCATTERING XSECTION RESULTANT OF COMPOUND (9) AND SHAPE ELASTIC (6)
3-004 TOTAL (N,N*) SCATTERING (9,10,11,12)
3-016 (N,2N) SCATTERING (13,14)
3-051 EXCITED DISCRETE (N,N*) LEVELS (1,9,10)
THRU EXCITED DISCRETE (N,N*) LEVELS (1,9,10)
3-064 EXCITED DISCRETE (N,N*) LEVELS (1,9,10)
3-091 (N,N*) LEVELS DESCRIBED BY CONTINUUM (9)
3-102 CAPTURE XSECTION BELOW 40KEV DUE TO RESOLVED AND UNRESOL-VED RESONANCES (4,5) UP TO 15MEV IN COMPETITION WITH EXCI TED LEVELS AND CORRECTED FOR ENERGY VARIATION OF GAMMA-ST-RENGTH FUNCTION (9,15) ABOVE 5MEV CONTRIBUTION FROM DIREC T AND COLLECTIVE CAPTURE (16,17)
3-102 METASTABLE STATE CAPTURE GIVEN AS HISTOGRAM BELOW 1,855EV OF 0,15164 LETHARGY WIDTH UP TO 4,15KEV 0,07713 DU ABOVE 4,15KEV XSECTION CONTINUOUS, ISOMERIC RATIO FROM PONITZ(18)
4-002 DIFF, ELASTIC CALCULATED BY MR BHAT FOR AG (NO EXP, DATA)
5-016 MAXWELLIAN EVAPORATION SPECTRUM FOR (N,2N)
5-091 MAXWELLIAN EVAPORATION SPECTRUM FOR (N,N*)

REFERENCES
1- CM LEDERER, JM HOLLANDER, I PERLMAN, 6TH ED(1967)
2- G CENACCHI, T/FIMA(68)4
3- THE MATTAUCH, W THIELE, AH WAPSTRA, NUCL,PHYS 67(1965)
4- AD CARLSON, MP FRICKE, UC-34 (6/1971)
5- P RIBON, CEA-N-1149 (1969)
6- ABACUS- EH AUERBACH, BNL-6562 (1964)
7- CA UTTLEY, KM DIMENT, AERE-PR/NP9 (1966)
8- W FOSTER, SCISRS FILE, (BNW-1967)
9- COMNUC- CL DUNFORD, A1-AEC-12931
10- MA ROTHMAN ET AL,,PHYS,REV,107,155(1957)
11- KK SETH, SCISRS FILE (DUKE-1965)
12- JP BUTLER, DC SANTRY, NEUT,XSECT,CONF,2,802(1968)
13- H BISSEM ET AL, EANDC(E)127U,P,38
14- HA TEWES ET AL, UCRL-6038-T (1960)
15- GGOD- AZ LIVOLSI, A PRINCE (NOT RELEASED)
16- FISPRO2= V BENZI, GC PANINI, G REFFO, CEC(69)24
17- G LONGO ET AL (TO BE PUBLISHED IN NUCL,PHYSICS)
18- W PONITZ, EANDC(E)66(U)

47-AG-107 1138 BNL TO BE PUBL. OCT71 M.R.BHAT AND A.PRINCE

SUMMARY DOCUMENTATION FOR THE EVALUATION OF ^{107}Ag, ^{109}Ag, AND ^{133}Cs

M. R. Bhat and A. Prince
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1. INTRODUCTION

This report describes the evaluation of Ag-107, Ag-109 and Cs-133 for the Evaluated Nuclear Data File, Version III (ENDF/B-III). The choice of the several pieces of experimental data used in the evaluation and the justification for such a choice are discussed in this report. The energy range covered by these evaluations is from 10^{-5}eV to $1.5x10^{7}$eV. The experimental data has been supplemented by the results of nuclear model calculations in the energy regions where such data were not available. These codes and the results of their calculations are described in the following pages.

2. LOW ENERGY CROSS SECTIONS

2.1. Resolved Resonance Parameters:

Ag-107, Ag-109

The most extensive measurements of the resonance parameters on the separated isotopes of silver are due to Muradyan and Adamchuk(1). These authors give the resonance parameters of Ag-107 up to 915 eV and for Ag-109 up to 903 eV. We have made use of these parameters as well as those recommended in BNL-325, 2nd Edition.(2) Resonance spins where available are indicated as given in the latter reference. The gamma widths given explicitly in BNL-325 for some resonances have been used; otherwise we have set Γ_γ = 0.140 eV. The nuclear radius used for Ag-107 is $0.71365x10^{-12}$ cm. which gives a σ_p = 6.4 barns; a value obtained in the measurements of Shull and Wollan.(3) This experimental value also agrees with the measurements of Zimmerman and Hughes(4) who obtained σ_p = 6.5±0.5 barns. The nuclear radius used for Ag-109 is

0.63×10^{-12} cm a value given by Chrien[5] from an analysis of the transmission data on low energy resonances. It is quite possible that some of the resonances given are p-wave resonances. However, since none of them has been specifically identified as such all the resonances have been grouped together as s-wave resonances.

Cs-133

We have used the resonance parameters of Cs-133 as given by Garg, et al.[6] The measured resonances extend up to an energy of 3.5 keV. The assumed value of Γ_γ was 0.110 eV. None of the resonance spins are known. Hence, we have put the resonance spins as 7/2; the spin of the target nucleus. The nuclear radius used here 0.75166×10^{-12} cm. Which corresponds to a σ_p = 7.1 barns as measured by Shull and Wollan[3]. Since none of these resonances has been designated as p-wave resonances we have listed all of them as s-wave resonances.

2.2. 2200 m/sec Neutron Capture Cross Section

Ag-107, Ag-109

We have used a value of 92 barns for the 2200 m/sec neutron capture cross section for Ag-109 as suggested by Walker.[7] The contribution to the capture cross section from the resonance parameters is 89.96 barns and we have added the difference as a 1/v contribution. For Ag-107 we have used a value of 36.8 barns for the capture cross section. This value was obtained by taking 63.4 barns for the capture cross section of natural silver as measured by Tattersall, et al[8] and calculating the contribution of Ag-107 by assuming 92 barns for Ag-109.

In the case of Ag-107 the resonance parameters contribution 2.56 barns for the capture cross section and the difference has been added on as a 1/v contribution.

<u>Cs-133</u>

The thermal capture cross section recommended by Walker[9] for this nucleus is 29.5 barns. We have used this value in the evaluation; this is made up of 16.06 barns from the resonance parameters and the rest being added on as a 1/v contribution.

3. HIGH ENERGY CROSS SECTIONS

3.1. Optical Model Parameters

The high energy cross section data available for these nuclei consists of capture and total cross section measurements over limited energy ranges with a few values of the (n, particle) reaction cross sections. Hence, the gaps in the experimental data have to be filled by nuclear model calculations. Therefore, one has to decide on a set of optical model parameters suitable for the nuclei under consideration. Such a choice of optical model parameters was made by fitting the total cross section data of Foster[9] for natural silver and cesium between 2.5 - 15.0 MeV. It is found that the optical parameters of Wilmore and Hodgson[10] give total cross sections which agree quite well with the experimental data. The calculations were done with the ABACUS-NBARREX Code.[11] The optical model parameters used are shown in Table I.

3.2. Capture Cross Sections

Ag-107

The calculations of the capture cross section of Ag-107 were done using the code COMMNUC by C. Dunford.[12] The excited states of Ag-107 used in these calculations are given in Table V along with their spins and parities. One other input data needed by this program is $2\pi \frac{\Gamma_\gamma}{\langle D \rangle} =$ 0.05965 where $\langle D \rangle$ is the average level spacing as determined from the neutron resonance parameter data for this nucleus. This parameter may also be considered as a normalizing parameter whose value is so adjusted as to get a fit to the experimental capture cross sections. In the case of Ag-107 we obtain a value of $2\pi \frac{\Gamma_\gamma}{\langle D \rangle} = 0.05965$ from the resonance parameters. However, it was found that the experimental capture data could be fitted with a value of 0.04029. The experimental data chosen for the fit was from Obninsk[13] from 29keV to 146keV and from the University of Wisconsin,[14] from 145 keV to 2.45 MeV. These measurements agree quite well with the Duke University[15] capture data above 60 keV or so though the Duke data seems to be consistently lower for lower energies. There is no experimental data on capture cross sections of Ag-107 at higher energies of 14-15 MeV. Hence, one could not estimate the contribution of direct and semi-direct capture at these higher energies. The capture cross section is therefore shown as a monotonically decreasing function of energy and is shown compared with the experimental data in Figure 1.

Ag-109

The experimental capture cross sections used for this isotope is again due to Kononov, et al.[13] from Obninsk. The cross section at 24 keV in this set agrees quite well with the single measurement due to Chaubey, et al.[16] However, all the values of capture cross sections in this set are lower than the Duke values as read off from their published curve. Also, if we combine the Obninsk values for Ag-107 and Ag-109 in the proportion of the natural abundance of these isotopes we get a capture cross section for natural silver which is about 16% lower systematically than the Karlsruhe measurements.[17] These discrepancies indicate need for further accurate measurements on separated isotopes of silver to resolve them. One could obtain a fit for the Obninsk capture data with $2\pi \frac{\Gamma_\gamma}{\langle D \rangle} = 0.02$ though the resonance parameters give a value of 0.0586. The calculated and experimental cross sections for Ag-109 are shown in Figure 2.

Cs-133

The most recent and careful measurements of the capture cross section of cesium in the keV region seem to be those due to Kompe[17] from Karlsruhe. We could fit this data by using $2\pi \frac{\Gamma_\gamma}{D} = 0.03831$; a value obtained from the resonance parameter data. The calculated and experimental cross sections are shown in Figure 3. In the case of this nucleus we do have an (n,γ) cross section measurement due to Qaim[18] at 14.8 MeV. Therefore calculations of the direct and semi-direct capture cross sections were made using FISSPRO Code of Benzi, et al.[19] and normalized to the experimental value of 7.1 mbarn at 14.8 MeV. This contribution to the capture cross section was added on to the capture cross section due to compound nuclear processes above 4.0 MeV.

3.3. Differential Elastic Scattering

Since there is no experimental data on the angular distribution of elastically scattered neutrons from these three nculei we used the ABACUS-NEARREX Code to calculate the angular distribution. The calculated cross sections were then fitted to a number of Legendre polynomials using the Code CHAD[20] to obtain the corresponding coefficients of a Legendre fit.

3.4. Inelastic Scattering

There is no experimental data on inelastic scattering for any of these three nuclei. The relevant cross section were therefore calculated using COMMNUC and the energy level scheme shown in Table II.

3.5. (n, particle) Reactions

Ag-107

Amongst all the measurements of the (n,2n) cross sections on Ag-107, there is only one experiment due to Minetti and Pasquarelli[21] who measure simultaneously the cross sections for populating the 6^+(T1/2 = 8.3 days) metastable state in Ag-106 as well as the 1^+(T1/2 = 24 min) ground state. They find these two cross sections to be 653 ± 30 mb and 870 ± 40 mb respectively at 14.7 MeV. We have chosen then values for normalizing the (n,2n) reaction cross section curve as calculated by Pearlstein[22] using the code THRESH. This code uses the standard evaporation model of a highly excited nucleus to calculate the various (n, particle) reaction cross sections. The cross sections calculated with this code using a Q = 9.531 MeV give a curve which passes through the experimental value of 1523 ± 70 mb at 14.7 MeV; hence we did not have to renormalize the calculated curve. Using the same code and Q = -0.752, -4.354 for the (n,p) and (n,α) reactions respectively the corresponding cross sections were calculated. Since there were no experimental data available on these reactions for Ag-107, the same normalization constants as had been used to normalize the calculated curves of Ag-109 to its experimental points were used here.

Ag-109

Minetti and Pasquarelli[21] obtained a cross section of 797 ± 50 mb for the (n,2n) reaction on Ag-109 leading to the 1^+ ground state of the final nucleus Ag-108. However, they did not measure the cross section leading to the 6^+ metastable state in the final nucleus. In the case of the (n,2n) reaction on Ag-107 we populate a 1^+ ground state and a 6^+ metastable state in Ag-106. The ratio of these two cross sections are 0.751. Since we have states of the same spin in Ag-108 we can assume the same ratio for these two cross sections. Assuming $\sigma^{(g)}$ = 797 we get $\sigma^{(m)}$ = 598 mb giving the total (n,2n) cross section as 1395 mb at 14.7 MeV. The (n,2n) reaction cross section curve as calculated from the THRESH code with Q = 9.182 MeV was normalized to this experimental value. Using the same code we also calculated the (n,p) cross section curve with a Q = 0.538 MeV. This curve was normalized to an experimental value of 15 mbarn at 14.5 MeV. This value was estimated from the measurements of Bayhurst and Prestwood[23] and Coleman.[24] The (n,α) cross section was similarly calculated with Q = -3.403 and the calculated curve normalized to a value due to Mukerjee, et al.[25]

Cs-133

The experimental values for the (n,2n) cross sections used in the evaluation are 1620 ± 150 mb at 14.8 MeV by Qaim[18] and 1598 ± 160 mb by Nagel[26] at 14.6 MeV. Their mean of 1609 mb was used to normalize the curve calculated using THRESH with Q = 9.038. The (n,p) cross section curve was calculated using a Q = 0.121 MeV and normalized to 10.5 mb at 14.8 MeV due to Qaim.[18] The (n,α) cross section values were similarly calculated with Q = -3.695 MeV and normalized to a mean of the experimental values of 1.96 ± .15 mb at 14.4 MeV due to Lu, et al.[27] and 1.14 ± .2 mb at 14.8 MeV due to Qaim.[18]

3.6. Energy Distributions of Secondary Neutrons

For the nuclei under consideration, energy distributions of secondary neutrons originating from (n,2n) processes and by inelastic scattering to a continuum of levels was also calculated. These energy distributions are expressed as normalized probability distributions. The energy distributions for these nuclei have been specified as an evaporation spectrum of the type

$$f(E \rightarrow E') = \frac{E'}{I} e^{-E'/\theta}$$

where I is the normalization constant and

$$I = \theta^2 \left[1 - e^{-(E-U)/\theta}\left(1 + \frac{E-U}{\theta}\right)\right]$$

Where θ is a temperature tabulated as a function of neutron energy E and U defines the upper limit for the final neutron energy such that $0 \leq E' \leq E - U$. To calculate θ as a function of neutron energy, we used the nuclear level density formulation of Gilbert and Cameron[28] with shell corrections. The basic idea of their approach is to match two types of level density formulae:

$$\rho_1 = \frac{1}{T} e^{(E-E_o)/T}$$

which holds true for energies lower than a characteristic energy E_x and

$$\rho_2 = \frac{\sqrt{\pi}}{12} \frac{\exp(2\sqrt{aU})}{a^{1/4} U^{5/4}} \frac{1}{\sqrt{2\pi}\sigma}$$

applicable to energies greater than E_x. E_x may be determindd from the nuclear systematics given in this paper and T and E_o are determined by fitting ρ_1 and ρ_2 at $E = E_x$. For energies where the formula ρ_2 is applicable the nuclear temperature τ is

$$\frac{1}{\tau} = \sqrt{\frac{a}{U}} - \frac{3}{2U}$$

where again a and U may be determined from the tables given by Gilbert and Cameron. In the low energy density expression, the nuclear temperature is considered a constant whereas in the high energy expression it is energy dependent as shown by the expression for τ.

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Table I. Optical Model Parameters

$$V(r) = Uf(r) + iWg(r)$$

$$f(r) = \left[1 + \exp(r-R)/a_U\right]^{-1}$$

$$g(r) = 4\exp\{(r-R)/a_W\}\left[1 + \exp(r-R)/a_W\right]^{-2}$$

$$r_o = 1.26\text{fm} \quad a_U = 0.66\text{fm} \quad a_W = 0.48\text{fm}$$

$$R = r_o A^{1/3}\text{fm}$$

$$U = 47.01 - 0.267 - 0.00118E^2 \text{ MeV}$$

$$W = 9.52 - 0.053 \text{ MeV}$$

Spin orbit term = 0.

Table II. Energy Levels

Ag-107		Ag-109		Cs-133	
E_{ex}(keV)	J^{π}	E_{ex}(keV)	J^{π}	E_{ex}(keV)	J^{π}
0.0	1/2-	0.0	1/2-	0.0	7/2+
93.0	7/2+	88.0	7/2+	81.0	5/2+
126.0	9/2+	133.0	9/2+	161.0	5/2+
325.0	3/2-	311.0	3/2-	384.0	3/2+
423.0	5/2-	415.0	5/2-	437.0	1/2+
787.0	3/2-	702.0	3/2-	633.0	9/2+
922.0	5/2+				
Continuum $\geq$ 950 keV		Continuum $\geq$ 710 keV		Continuum $\geq$ 650 keV	

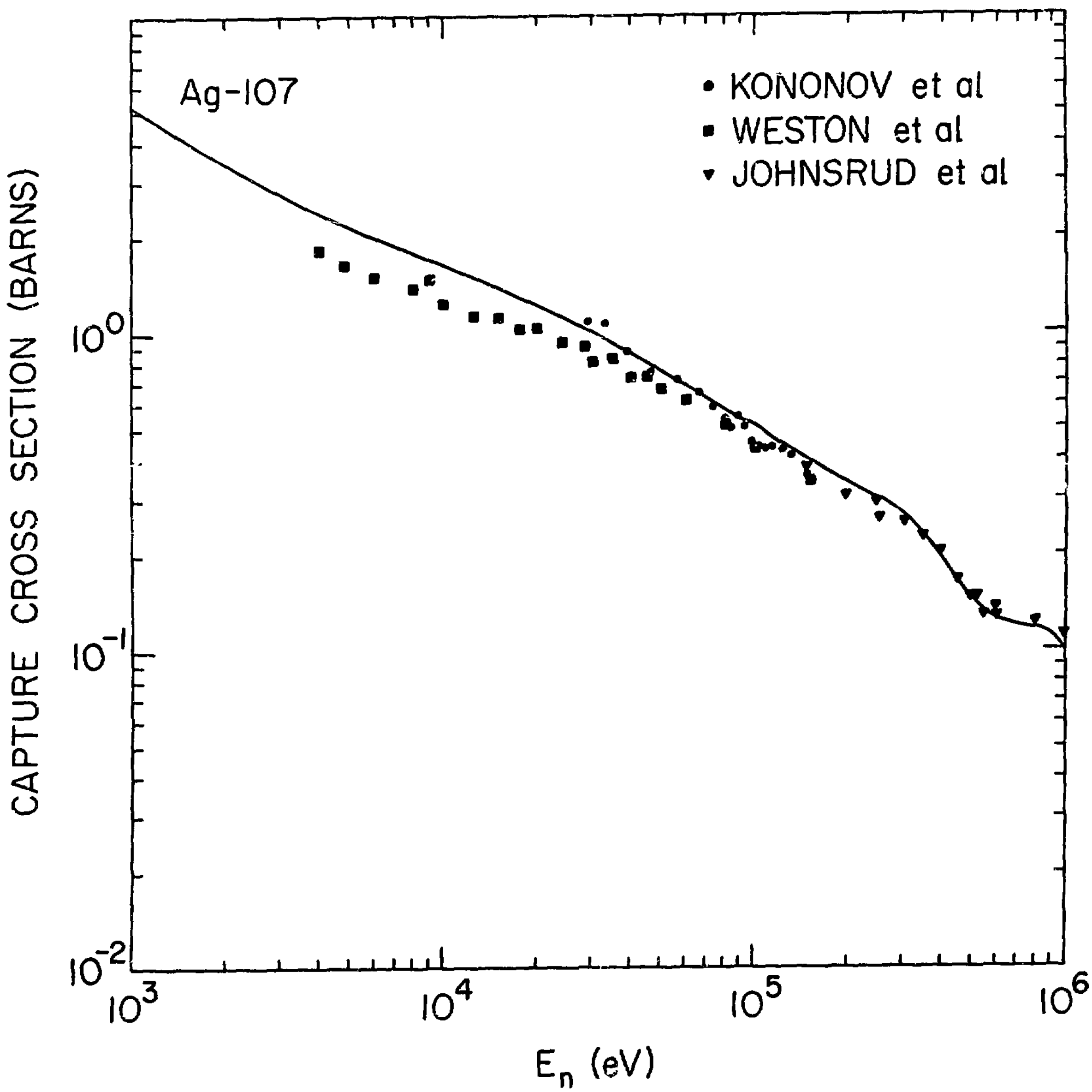
Ag-107
KONONOV et al
WESTON et al
JOHNSRUD et al
CAPTURE CROSS SECTION (BARNS)
10^0
10^{-1}
10^{-2}
10^3
10^4
10^5
10^6
E_n (eV)

Fig. 1

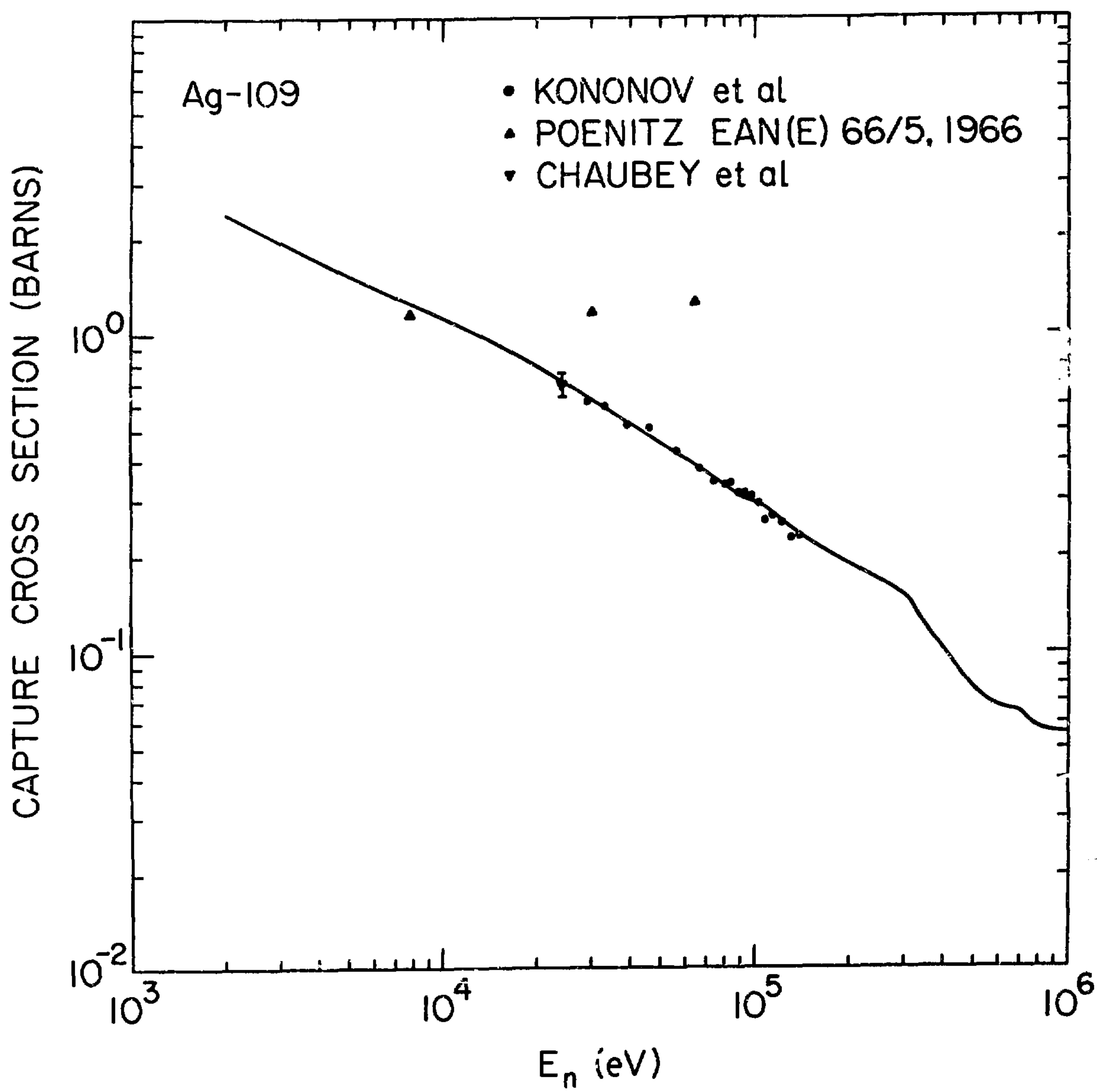
Ag-109
• KONONOV et al
▲ POENITZ EAN(E) 66/5, 1966
▼ CHAUBEY et al
CAPTURE CROSS SECTION (BARNS)
10^0
10^-1
10^-2
10^3
10^4
10^5
10^6
E_n (eV)

Fig. 2

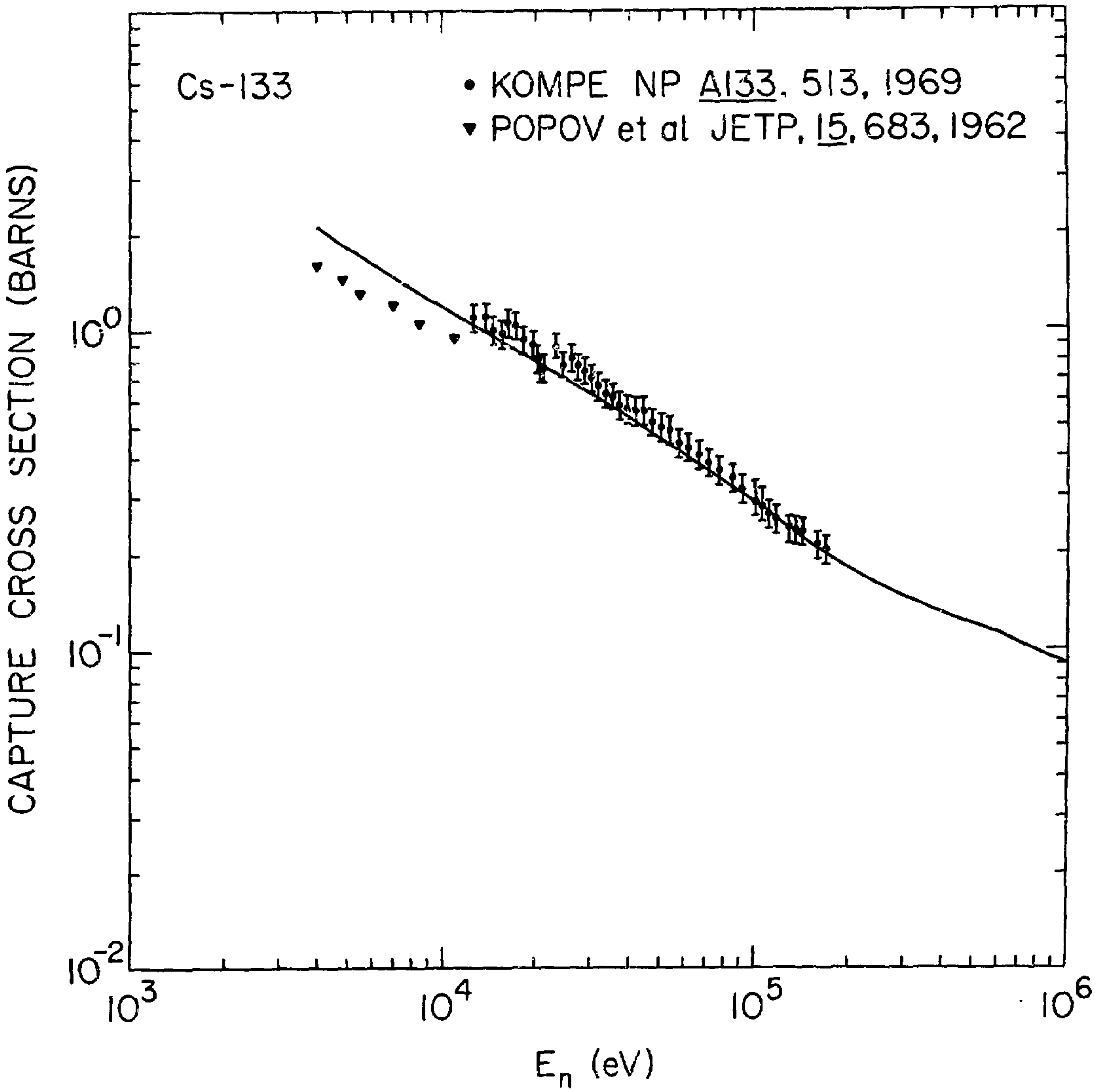
Cs-133
• KOMPE NP A133, 513, 1969
▼ POPOV et al JETP, 15, 683, 1962
CAPTURE CROSS SECTION (BARNS)
10^0
10^-1
10^-2
10^3
10^4
10^5
10^6
E_n (eV)

Fig. 3

54-XE-135 1026 BNW PRI.COMM.1967 JUN67 B.R.LEONARD.K.B.STEWART

XENON-135

General Identification

MAT = 1026
ZA = 54135.0
AWR = 133.748

[Everling, 1960] (1)

$$\frac{Xe^{135}}{N} = \frac{134.907}{1.008665}$$

Radioactive Decay

$T_{\frac{1}{2}}$ = 9.13 hr. [Nuclear Data Tables] (2)
λ (derived) = 2.108E - 05

Cross Section Evaluations

A careful study of the low-energy cross section has been done by [Sumner].(3) The results of this study were accepted in the apparent absence of any controversy. [Sumner] lists point values from 0.01 to 1000 eV for 20°C. For the ENDF/B tabulation it was decided to tabulate data for 0°K. Therefore, the parameters of [Sumner] were used to generate point values from 10^{-4} to 10^3 eV using the program UNICORN [Otter].[4] In the UNICORN calculation a Xe^{135} mass of 10^4 was used since laboratory energy parameters were used. This calculation gives

$$\sigma_{n,\gamma} = 2.637 \times 10^6 \text{ barns at } 0.0253 \text{ eV } (0^\circ K)$$

compared with

$$\sigma_{n,\gamma} = 2.652 \times 10^6 \text{ barns } (20^\circ C) \text{ [Sumner].}$$

ENDF/B

The data file contains 51 point values for each of σ_T(MT=1), σ_n(MT=2), and σ_γ(MT=102). The energy range covered 10^{-4} to 10^3 eV. The energy mesh is calculated by UNICORN to minimize error in a Lnσ vs E interpolation.

$$a = 0.746 \times 10^{-12} \text{cm}$$

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62-SM-149 1027 BNW PRI.COMM.1967 JUN67 B.R.LEONARD.JR. AND K.B.STEWART

SAMARIUM-149

General Identification

MAT = 1027
ZA = 62149.0
AWR = 147.638
I = 3.5

[Everling][1]

$$\frac{MSm^{149}}{Mn} = \frac{148.9169}{1.008665} = 147.638$$

Introduction

The primary objective of establishing the data file for Sm-149 was to provide a best estimate of cross sections in the thermal and epithermal energy range for the calculation of absorptions in thermal systems. The ENDF/B entries as of this date consequently include smooth cross sections in the thermal region, resonance parameters from 3.55 to 100 eV, and average parameters for the region of 100 eV to 10,000 eV.

Cross Sections

Low-Energy

Although a great deal of effort has gone into measurement of resonance parameters of Sm^{149}, there is a paucity of precise data in the thermal region. The measurements which exist show that although the resonance at 0.0976 eV dominates the thermal region there is a significant contribution from a bound level (~10% at 0.025 eV). The parameters of the bound level have never been precisely determined. [Pattenden][2], for example, added a 1/v component which gave much too large a contribution in the low cross section regions between resonances at higher energies. To establish the low energy behavior the following data sources were considered:

Source	Sample	Energy Range
Pattenden (2)	Sm^{149}	0.01 - 1 eV
McReynolds (3)	Sm	0.005 - .2 eV
Sailor (4)	Sm	0.04 - 1 eV
Marshak (5)	Sm	0.06 - .19 eV

The following resonance parameters of [Marshak] (5) were then used in the program UNICORN (6) to calculate the cross section throughout the thermal range:

E_o	Γ_n^o	Γ_γ	J	R
0.0976 eV	1.642 meV	63.6 meV	4	$.5093 \times 10^{-12}$ cm
0.873	0.7747	59.9	4	.5093

The resonance parameters listed in file 2 were also used in the calculation. The calculated cross section was then used with the measured data listed above, corrected for the contributions of other Sm isotopes where necessary, to establish the residual cross section. The residual cross section was then fitted by standard graphical techniques to establish the parameters of the bound level. The resulting fit was not very precise but was well within the rather large scatter of the data. The following resonance parameters were derived:

E_o	Γ_n^o	Γ_γ	J	R
-0.285 eV	2.167 meV	64 meV	3	$.5093 \times 10^{-12}$ cm

The value of Γ_γ, of course, could not be determined for a level so fa removed but was input as the approximate average value of the lowest-lying resonances. Similarly, the value of J = 3 was input, having been determined by others. (7)

The negative energy resonance parameters were then added to the UNICORN input. The resulting cross sections were recalculated, found to be in reasonable agreement with expectations and no further adjustment was made. The calculated cross sections gave the following values for σ_γ at 0.0253 eV:

	ENDF/B	[BNL-325(1966)][7]
Sm^{149}	41,200	41,000 ± 2,000
Sm	5,780	5,820 ± 100

The ENDF/B data file consists of 82 point values for σ_T (MT=1), σ_n (MT=2), and σ_γ (MT=102) over the energy range 10^{-4} to 3.554 eV. The point values were calculated by UNICORN for 0^oK. Sm^{149} was given a mass of 10^4 in the calculations to remove the center-of-mass term. Lnσ vs E interpolation is specified because the energy mesh calculated by UNICORN is designed for minimum interpolation error in that fashion. Point values were continued to the minimum cross-section region (3.554 eV) between the 0.873 eV and 4.98 eV resonances to minimize discontinuities from joining smooth cross section values to values calculated from resonance parameters in the presence of interference.

Smooth cross sections in the resonance region 3.554 eV to 10^4 eV are specified to be zero in the ENDF/B file.

Resonance Region

Resolved

A preliminary version of [BNL-325 (1966)][7] lists resonance parameters for 27 resonances from 4.98 to 99 eV. The recommended parameters were used in most cases except where rounding had reduced precision. In the case of the 4.98 eV resonance the recommended value[7] of Γ_n^o = 0.90 meV is inconsistent with the determination of J = 4. The value used in the ENDF/B file of Γ_n^o = .7854 meV is consistent with the results of Marshak.(5) In the case of the 9.0 eV resonance the value given by Marshak(5) and quoted in [BNL-325 (1966)](7) for Γ_n^o is in error. The correct Marshak value, for J = 4, of Γ_n^o = 3.093 meV is used in the ENDF/B data file. This corrected value is to be applied to the value of Γ (not to Γ_γ as done in Ref 7) to obtain the value of Γ_γ = 58.6 meV used in the ENDF/B file.

In the ENDF/B file the value of J = I = 3.5 was used to generate the value g = .5 for those resonances where J has not been determined.

<u>Unresolved</u>

The transmission coefficient constant was determined from

$$\rho = c\sqrt{E} = kR = 1.118.10^{-3}\sqrt{E}.$$

The following average parameters were specified in ENDF/B as determined from the resolved parameters and assuming the same values for J = 3 and J = 4 resonances:

$$D = 6.8 \text{ eV}$$
$$< \Gamma_n o > = 5.1 \times 10^{-3} \text{ eV}$$
$$< \Gamma_\gamma > = 62 \text{ meV}$$

where the value of $< \Gamma_\gamma >$ was determined from the average of the lowest energy resonances where precise determinations exist. The high-energy cutoff of the unresolved region was arbitrarily set at 10^4 eV in ENDF/B.

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63-EU-151 1028 BNW PRI.COMM.1970 JUN70 B.R.LEONARD.JR. AND K.B.STEWART

EUROPIUM-151

General Identification

MAT = 1028
ZA = 63151.0
AWR = 149.623 [Everling](1)
R = $.63 \times 10^{-12}$ cm [Nereson](2)
I = 2.5

Radioactive Decay

MT = 16	$Eu^{150} \rightarrow Gd^{150}$	$= 1.375 \times 10^{-5}\ sec^{-1}$	Ref 3
	$Gd^{150} \rightarrow Sm^{146}$	$= 1.234 \times 10^{-14}\ sec^{-1}$	Ref 4
MT = 17	$Eu^{149} \rightarrow Sm^{149}$	$= 7.567 \times 10^{-8}\ sec^{-1}$	Ref 5
MT = 102	$Eu^{152} \rightarrow Sm^{152}$	$= 1.77 \times 10^{-9}\ sec^{-1}$	Ref 5
MT = 103	$Sm^{151} \rightarrow Eu^{151}$	$= 2.35 \times 10^{-10}\ sec^{-1}$	Ref 5
MT = 107	$Pm^{148} \rightarrow Sm^{148}$	$= 1.485 \times 10^{-10}\ sec^{-1}$	Ref 4

Introduction

The primary objective was to provide for ENDF/B a set of evaluated data in the thermal and resonance region for the calculation of absorptions in (near-) thermal reactors. Due in part to the stimulus of being provided calculated n,2n and n,3n cross sections some data have been provided for the fast-neutron energy range. These are the total and capture cross sections in addition to the n,2n and n,3n cross sections. These values will constitute a basis for model calculations to complete the set for this isotope.

Cross Sections

Low Energy

No existing evaluation as such was discovered. Consequently the following data sets were considered in arriving at a fit to the low-energy cross section:

Ref	Sample	Energy Range
Tassan[6]	Eu^{151}	.2 - .7 eV
Sailor[7]	Eu	.08 - .8 eV
Pattenden[8]	Eu^{151}	.01 - 6 eV
Holt[9]	Eu^{151}	10^{-4} - 10^{-2} eV
Sturm[1]	Eu	.007 - .1 eV

These data are observed to be badly discrepant, e.g., the values of Pattenden and Holt differ by 50% at 10^{-2} eV. No definite reason for this discrepancy was established. Most of the cross section at thermal energies (~80% at .025 eV) is due to a bound level. In order to analyze this level a calculation was made of the resonance contribution using the program UNICORN.[11] In this calculation the resonance parameters listed in file 2 were used along with the parameters established for the first two levels by [Tassan].[6] The parameters of Tassan were accepted as the most accurate measurements and were adjusted to conform to the presently established value of J = 3 for the first four resonances[12] (including the bound). The parameters used are listed below:

E_o	Γ_n	Γ_γ	J	R
0.321 eV	.07139 meV	79.53 meV	3	$.63 \times 10^{-12}$ cm
0.46	.665	87.34	3	$.63 \times 10^{-12}$ cm

The residual cross section was then calculated correcting for the rather small contribution of Eu^{153} using the Eu^{153} values listed in ENDF/B MAT 1029. The residual cross section was fitted to a single-level B-W using standard graphical techniques. The chosen fit favors the data of Sturm and Holt and disagrees significantly with the data of Pattenden for energies less than about 0.06 eV. The agreement with the data of Sturm for energies less than about 0.04 eV is of little significance since the correction for higher-order neutrons in that measurement was in error. An equally good fit of a bound level could have been made to the data of Pattenden. Measurements made in thermalized spectra seemed, however, to favor the higher values of Holt and the resulting fit falls only slightly below those data.

The parameters derived for the bound level were:

$$E_o = -0.0006 \text{ eV}$$
$$\Gamma_n = 2.58 \times 10^{-6} \text{ eV}$$
$$\Gamma_\gamma = 0.100 \text{ eV}$$
$$J = 3$$
$$R = .63 \times 10^{-12} \text{ cm}$$

The values of J and R were, of course, not determined but were input. The value of Γ_γ was determined but not very precisely because of the discrepant data. This value of Γ_γ differs significantly from the value of 67 meV deduced by Holt.(9) This difference is meaningless, however, since it was not possible to deduce a significant value of Γ from Holt's data since the measurement only covered an energy range of about 1/10 Γ near the peak of the resonance. A much wider resonance was required to contribute to the energy region of 0.2 to 0.3 eV.

The low-energy cross sections in the ENDF/B file 3 for σ_T(MT=1), σ_n(MT=2), and σ_γ(MT=102) were calculated from the resonance parameters given in this discussion for the -0.0006 eV, 0.321 eV, and 0.46 eV resonances plus the resonances listed in file 2. The calculations were made by UNICORN for 0^oK and with a mass of Eu^{151} of 10^4 to remove the center-of-mass term in UNICORN. Sixty-seven (67) point values are listed for each reaction over the energy range 10^{-4} to 0.84 eV.

The calculated value of σ_γ at .0253 eV is 9350 barns compared with a recommended value of 8800 ± 100 barns given in [BNL-325 (1966)].(13) Since we have not calculated any spectrum-averaged cross sections with the ENDF/B cross section we have not established any significance to this difference.

Resonance Region

A preliminary draft of [BNL-325 (1966)](13) gives resonance parameters for 25 resonances from 1.055 to 27 eV. The recommended values given there are listed in ENDF/B with few exceptions. These exceptions occur for the 1.055 eV and 3.368 eV resonances where the very precise measurements of Domanic(14) have been used along with the J factors(12) which were determined after the measurements of Domanic. Note that the values recommended in BNL-325 for Γ_n and Γ_n^o for the 1.055 eV resonance have not been adjusted for the value of J = 3 as implied.

The resonance parameters as described are listed in file 2 of ENDF/B. The value of J = I = 2.5 has been prescribed for those resonances where the value of J has not been determined in order to generate the value of g = .5. A value of 11.9 $E^{-\frac{1}{2}}$ b has been added to the smooth cross sections of σ_T and σ_γ in file 3 from 0.84 to 28 eV to account for the effects of the bound level.

Unresolved resonance parameters are prescribed in file 2 from 28 eV to 1.6 x 10^5 eV. The values listed are taken as the same for J = 2 and J = 3 and specified for L = 0. The values were obtained from averages of the resolved parameters and are:

$$\rho = c\sqrt{E} = kR = 2.77 \times 10^{-3}\sqrt{E}$$

$$D_J = 1.5 \text{ eV}$$

$$\langle \Gamma_n^{\circ} \rangle = 0.4 \times 10^{-3} \text{ eV}$$

$$\langle \Gamma_\gamma \rangle = .092 \text{ eV}$$

Fast-Neutron Region

Values of σ_T(MT=1), σ_γ(MT=102), $\sigma_{n,2n}$(MT=16), and $\sigma_{n,3n}$(MT=17) are given in file 3 from 1.6 x 10^5 eV to 20 MeV. The values of $\sigma_{n,2n}$ and $\sigma_{n,3n}$ were calculated by Pearlstein.[15] The values of σ_γ were taken from a smooth curve through the data of Johnsrud[16] and extrapolated by intuition to higher energies. The values of σ_T were taken from a smooth curve drawn through recent data of Foster and Glasgow[17] for natural europium and extrapolated to lower energies by comparison with the data for neighboring nuclei.

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63-EU-153 1029 BNW PRI.COMM.1967 JUN67 B.R.LEONARD,JR. AND K.B.STEWART

EUROPIUM-153

General Identification

MAT = 1029
ZA = 63153.0
AWR = 151.607 [Everling](1) $\frac{152.9207}{1.008665}$
R = .63 x 10^{-12} cm [Nereson](2)
I = 2.5

Radioactive Decay

MT = 16	$Eu^{152} \rightarrow Sm^{152}$	$\lambda = 1.77 \times 10^{-9}$ sec^{-1}	Ref 3
MT = 102	$Eu^{154} \rightarrow Gd^{154}$	$\lambda = 1.37 \times 10^{-9}$ sec^{-1}	Ref 3
MT = 103	$Sm^{153} \rightarrow Eu^{153}$	$\lambda = 4.10 \times 10^{-6}$ sec^{-1}	Ref 3
MT = 107	$Pm^{150} \rightarrow Sm^{150}$	$\lambda = 7.13 \times 10^{-5}$ sec^{-1}	Ref 4

Introduction

The primary objective was to provide for ENDF/B a set of evaluated data in the thermal and resonance region for the calculation of absorptions in thermal and near-thermal reactors. Since calculated values of n,2n and n,3n cross sections were provided some other data were also provided in the fast neutron energy range. These are the total and capture cross sections in addition to the n,2n and n,3n. These values will provide a basis for model calculations to complete the set for this isotope.

Cross Sections

Low Energy

No existing evaluation as such was discovered. The only known measurements of the total cross section in the low energy range which was made with a sample enriched in Eu^{153} was that of Pattenden.(5) These measurements showed that the thermal cross section of Eu^{153} was only about one-tenth that of natural europium. In addition the measurements showed that the low energy cross section of Eu^{153} was dominated by a bound level (~85% of the cross section at 0.025 eV). However, Pattenden did not present an analysis of the results in terms of bound level parameters. It was felt desirable to make such an analysis in order to minimize possible spurious structure in the data and provide an extrapolation beyond the range of measurement.

The program UNICORN[6] was used to calculate the resonance contribution in the thermal region. The resonance parameters listed in file 2 were used along with the parameters of Pattenden for the 0.457 eV resonance:

$$E_o = 0.457 \text{ eV}$$
$$2g\Gamma_n = 0.010 \text{ eV}$$
$$\Gamma_\gamma = 59 \text{ meV} .$$

The calculated resonance contribution was subtracted from the data of Pattenden and the residual cross section was analyzed for bound level parameters using standard graphical techniques. The residual cross section could not be fitted adequately to a single bound level and two levels were invoked. The results of the analysis gave the following parameters for the bound levels:

E_o	$2g\Gamma_n$	Γ_γ
-018 eV	0.8477 meV	.10 eV
-0.007 eV	$1.387 \cdot 10^{-7}$ eV	.050 eV

These parameters were then added to those previously used in UNICORN to calculate 58 point values of σ_T(MT=1), σ_n(MT=2), and σ_γ(MT=102) from 10^{-4} eV to 0.77 eV. These values are given in file 3 with $\ell n\sigma$-E interpolation since the energy mesh calculated in UNICORN is designed to give minimum interpolation error in $\ell n\sigma$ vs E. The point values are for 0^oK.

The resulting calculation gives a total cross section at 0.0253 eV of 457.5 barns in agreement with Pattenden's value of 456 ± 16 barns. BNL-325 (1966)[7] gives a recommended value of 370 ± 60 barns for σ_γ (.0253). This value is based in part on measurements made in a thermalized spectrum. Since we have not made spectrum-averaged calculations using the ENDF/B cross sections, the significance of this difference is not known at present.

Resonance Region

BNL-325 (1966) lists parameters for 18 resonances from 1.73 eV to 24 eV. For the first four resonances we have used the precise parameters determined by Domanic which differ from the recommended parameters primarily because of rounding. The parameters of the 18 resonances are listed in file 2. The value of $J = I = 2.5$ is specified for all of the resonances except the 2.456 eV resonance where $J = 3$ has been determined.[8]

Parameters for the unresolved region were calculated from the resolved parameters. The average value of $< 2g\Gamma_n^{\ o} >$ is 0.6×10^{-3} eV. There are 20 resonances observed in 24.9 eV which give an average spacing of 2.5 eV (spin state)$^{-1}$. The value of c was calculated from:

$$\rho = c\sqrt{E} = kR = 2.77 \times 10^{-3}\sqrt{E}.$$

It was assumed that the average parameters are the same for each spin state and the unresolved region was specified from 26 eV to 1.6×10^5 eV for L = 0 neutrons. The smooth cross section file specified zero cross sections for all reactions throughout the resonance region (.77 eV to 2×10^5 eV).

Fast-Neutron Region

The total cross section given in file 3 from 1.6 x 10^5 to 20 MeV is the same as that given for Eu^{151} (MAT 1028) since the measurements were for natural europium. The capture cross section is also the same although the measurements were for Eu^{151}. The n,2n and n,3n cross sections were calculated by Pearlstein.(9)

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64-GD 1030 ANL ANL-7387 (MAR 68) OCT66 E.M.PENNINGTON, J.C.GAJNIAK

V. Gadolinium (MAT 1030)

E. M. Pennington
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A. Outline of Cross Sections Included

File 3 contains smooth total, elastic, inelastic, (n,2n), (n,3n) and (n,γ) cross sections, along with values of μ_L, ξ and γ calculated from the Legendre coefficients of File 4. The energy range covered extends from 0.001 eV to 15 MeV.

Resolved resonance parameters for 24 resonances in Gd-155 and 5 resonances in Gd-157 are included in File 2, with the resonance calculations extending from 0.001 eV to 50 eV.

Legendre coefficients for elastic scattering in the center of mass system for 32 energies and the transformation matrix from the center of mass to laboratory systems are included in File 4.

Nuclear temperatures are given in File 5 for inelastic scattering and for the (n,2n) and (n,3n) reactions. No resolved levels were considered for inelastic scattering.

Free gas thermal scattering law parameters are given in File 7.

B. Sources of Gadolinium Data

The chief source of gadolinium data was the recent Karlsruhe evaluation (Ref. 1). Data from other sources were also used as described in detail in the following.

Total Cross Section

The total cross section up to 50 eV is calculated entirely from resonance parameters. From 50 eV to 10 keV, σ_{nT} was read from the

BNL-325 graphs (Ref. 2). Values from 10 keV to 10 MeV were obtained from KFK-352 (Ref. 1). The total cross section was extended from 10 to 15 MeV using the sparse data of Ref. 2 as a guide.

Elastic Scattering Cross Section

Below 50 eV, the elastic scattering cross section is calculated from the resonance parameters of File 2. From 50 eV to 10 keV, the total cross section was split into scattering and capture components using a computer program based on Equations (39), (40), (43) and (44) of KFK-352. Equations (39) and (40) are expressions for the average scattering and capture cross sections for $\ell = 0$ neutrons in the unresolved resonance region for Gd-155. The parameters used in these equations were determined by averaging the known resonance parameters. Since not enough resolved parameters are known to find average parameters for the other isotopes, Gd-155 was assumed typical of natural gadolinium. Equations (43) and (44) merely use Equations (39) and (40) to split the experimental σ_{nT} into the scattering and capture components.

From 10 keV to 10 MeV, values of σ_{nn} were obtained from KFK-352. The reaction cross section was subtracted from the total cross section to give the elastic scattering cross section from 10 to 15 MeV.

(n,γ) Cross Section

The (n,γ) cross section is calculated from resonance parameters below 50 eV. From 50 eV to 10 keV, $\sigma_{n\gamma}$ was determined as described above in the discussion of the elastic scattering cross section. Values from KFK-352 were used from 10 keV to 10 MeV, with the extension to 15 MeV being made on the basis of linear extrapolation on a log-log scale.

Inelastic Scattering Cross Section

The inelastic scattering cross section was obtained up to the threshold of the (n,2n) reaction from KFK-352. From the (n,2n) threshold to 10 MeV, $\sigma_{n,2n}$ was subtracted from the $\sigma_{nn'}$ of KFK-352 to give the inelastic scattering cross section. From 10 to 15 MeV, the reaction cross section of KFK-352 was extrapolated on a basis of a value at 15 MeV equal to 1.01 times the sum of $\sigma_{n,2n}$, $\sigma_{n,3n}$ and $\sigma_{n\gamma}$. Then $\sigma_{nn'}$ from 10 to 15 MeV was obtained by subtracting the other reactions from this total reaction cross section.

(n,2n) and (n,3n) Cross Sections

The (n,2n) and (n,3n) cross sections were both calculated by S. Pearlstein, according to the methods of Ref. 3.

μ_L, ξ and γ

The values of μ_L, ξ and γ were calculated from the File 4 Legendre coefficients, as described in the magnesium documentation.

Resonance Parameters

Resonance parameters are included for 24 s-wave resonances in Gd-155 and 5 s-wave resonances in Gd-157. The parameters for the first three resonances in Gd-155 and the first two in Gd-157 are from Ref. 4. Parameters for the remaining resonances are from BNL-325 (Ref. 2).

Elastic Scattering Legendre Coefficients

Legendre coefficients in the center of mass system, which were obtained from H. Alter (Ref. 5), were used in the energy range from

0.3 to 1.5 MeV. Below 0.3 MeV, coefficients were estimated from extrapolation of the Alter data, with isotropic scattering assumed below 5 keV. Above 1.5 MeV, coefficients were calculated at seven energies by performing Abacus-2 (Ref. 6,7) calculations and fitting the resulting shape elastic angular distributions with the Argonne SAD code (Ref. 8). The parameters used in these optical model calculations were derived from approximations to Eq. (35) of Ref. 9, since the optical model parameters used in KFK-352 were also obtained in this manner. This equation is used to obtain local parameters which are approximately equivalent to non-local ones. As in KFK-352, the parameters of Table 4 of Ref. 9 without the spin-orbit term were used for the non-local parameters.

The transformation matrix from the center of mass to laboratory systems, calculated using CHAD (Ref. 10), includes elements through ℓ = 19 in agreement with the number of coefficients in the high energy Legendre expansions.

Secondary Energy Distributions

Nuclear temperatures for inelastic scattering, calculated from the prescription of Ref. 11, are given at 60 keV and 15 MeV. Only continuum inelastic scattering was considered, both in this evaluation and in KFK-352, since there are many low-lying levels in the various Gd isotopes above the (n,n′) threshold.

Nuclear temperatures are given for the (n,2n) and (n,3n) reactions. These were determined by the methods described under magnesium and molybdenum.

Thermal Neutron Scattering Law

The free gas thermal scattering law in File 7 has a cutoff of 1.5 eV above which the static model is used, and a value of 8.0 barns for the free atom scattering cross section. This 8.0 barn value is that which is calculated from resonance parameters near 1.5 eV.

C. Comments on Gadolinium Cross Sections

The cross section of gadolinium in the thermal energy range is the largest of any stable element. The resonance parameters of Ref. 4, which were used in this evaluation, give a very good fit to the gadolinium cross section at low energy.

There is not a great deal of experimental data available for gadolinium above one or two MeV. Thus optical model calculations were used to a large extent at higher energies. The (n,2n) and (n,3n) cross sections are also based entirely on calculation. No (n,p) and (n,α) cross sections are included in this compilation, but the Coulomb barrier is sufficiently high to make these cross sections quite small.

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66-DY-164 1031 BNW PRI.COMM.1967 JUN67 B.R.LEONARD.JR. AND K.B.STEWART

DYSPROSIUM-164

General Identification

MAT = 1031
ZA = 66164.0
AWR = 162.52 [Everling][1] $\frac{163.9281}{1.008665} = 162.52$
I = 0
R = $.77 \times 10^{-12}$ cm Ref. 2

Radioactive Decay

MT = 102 $Dy^{165} \rightarrow Ho^{165}$ $\lambda = 8.309 \times 10^{-5}\ sec^{-1}$ Ref 3.

Cross Sections

Low Energy

The cross sections of Dy^{164} are rather non-controversial. The July 1, 1966, edition of CINDA[3] shows three monoenergetic measurements: 1) σ_T measured from 10^{-3} to 1.5×10^{-2} eV by Moore[4], 2) σ_T and σ_{act} measured from .02 to 1.5 eV by Sher[5] and 3) resonance parameters for a resonance at 146 eV by Zimmerman.[6]

Sher used his data and those of Moore to derive parameters for the bound level that dominates the thermal cross section. The parameters quoted by Sher are rather confusing. He quotes a value of $\Gamma = 166 \pm 4$ meV. Since the resonance is at -1.89 eV the analysis is very insensitive to the value of Γ. Consequently we have refitted the data preserving the quoted parameters as much as possible, particularly hoping to improve the fit to the activation cross section. We found no significant improvement. Our derived parameters are:

$$E_o = -1.89$$
$$\Gamma_n^o = 0.0420 \text{ eV}$$
$$\Gamma_\gamma = 0.0538 \text{ eV}$$
$$R = .77 \times 10^{-12} \text{ cm}$$

where the value of Γ_γ was chosen to agree with the value obtained for the 146 eV resonance.

The program UNICORN[7] was used to calculate the low-energy cross sections using our parameters for the -1.89 eV resonance and the parameters of Zimmerman for the 146 eV resonance. The calculation was done for $0^{\circ}K$ and the center-of-mass term removed from UNICORN. The point values are given in file 3 as 40 values from 10^{-4} to 2.229 eV. Lnσ-E interpolation is specified.

Resonance Region

The parameters of Zimmerman for the 146 eV resonance are given in file 2. The resolved resonance region is specified from 2.229 to 272 eV. The smooth cross section file is specified to be zero in this energy range.

The UNICORN calculation yields a capture resonance integral of 352 barns from 0.45 eV to 10^3 eV. This is to be compared with a recent measured value of 377 ± 34 barns.[8]

Fast-Neutron Region

Foster and Glasgow[9] have recently measured the total cross section of elemental dysprosium from 3 to 15 MeV. These results form the basis for 18 point values given in file 3 from 3 to 20 MeV.

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71-LU-175 1032 BNW PRI.COMM.1967 JUN67 B.R.LEONARD.JR. AND K.B.STEWART

LUTETIUM-175

General Identification

MAT = 1032
ZA = 71175.0
AWR = 173.438 Ref 1. $\frac{174.9409}{1.008665}$
I = 3.5
R = $.73 \times 10^{-12}$ cm Ref 2.

Radioactive Decay

MT = 102 Lu $176^m \rightarrow Hf^{176}$ $\lambda = 5.20 \times 10^{-5}$ sec^{-1} Ref 3

Introduction

The primary objective was to provide a set of evaluated data for low-energy neutrons since the primary interest in Lu-175 is in application as a neutron spectrum indicator. However, since new data were available on the fast-neutron total cross sections we have also entered σ_T and σ_γ in the fast-neutron range. Hopefully these data will provide a basis for model calculations to complete the data set on this nucleus.

Cross Sections

Low Energy

Although Lu^{175} is the major isotope in elemental Lutetium (97.41%) the Lu^{175} cross section at low energies constitutes only about 1/3 of the elemental cross section. In a literature search through July 1, 1966 [CINDA][4] we have found only one attempt to establish the low energy cross section of Lu^{175}. In this work of [Baston][5] measurements of σ_T were made over the energy region 0.01 to 1.0 eV with a time-of-flight spectrometer. The authors made no attempt to fit the observed cross section but presented a best fit 1/v behavior from which they inferred a value of σ_γ (.0253 eV) = 23 ± 3 barns. The data which they presented were, however, noticeably non-1/v. Consequently, we have fitted these data in order to provide an imporved estimate of the energy variation of the cross section. The resonance parameters given in file 2 were used to calculate the resonance contribution to the low energy cross section using the program UNICORN. The residual cross section was than analyzed by standard graphical techniques to obtain parameters for a bound level. Our evaluation of the parameters gives:

$$E_o = -.1785 \text{ eV}$$

$$2g\Gamma_n = 3.907 \times 10^{-6} \text{ eV}$$

$$\Gamma_\gamma = 0.060 \text{ eV}$$

$$R = .73 \times 10^{-12} \text{ cm}$$

The values of R and Γ_γ are, of course, input values. The resonance is sufficiently far removed that the analysis is insensitive to the value of Γ_γ so we have used the value established for the observed parameters.

The parameters of the bound level plus the parameters contained in file 2 were used to calculate the final cross section. The calculations as performed by UNICORN for 0^oK. The results of the calculations are given in file 3 as 33 point values for σ_T(MT=1), σ_n(MT=102), and σ_γ(MT-102) over the energy range of 10^{-4} to 1.075 eV.

The results of these calculations gave the following values at E = .0253 eV:

$$\sigma_T = 28.2 \text{ barns}$$

$$\sigma_\gamma = 23.5 \text{ barns}$$

$$\sigma_p = 4.7 \text{ barns}$$

The cross section values in the low energy range which are calculated for elemental lutetium using the ENDF/B data for Lu^{175} and Lu^{176} are seriously discrepant with recent total cross section measurements.[2,7] The contribution of Lu^{175} to the elemental cross section is so small that it would require a factor of 2 or more error in the absolute scale of the Lu^{175} cross section to explain the discrepancy.

Resonance Region

No new information on the resonance parameters of Lu^{175} has appeared[4] since the 1960 Supplement to BNL-325.[8] The parameters for the 16 resonances extending from 2.61 to 57.4 eV are given in file 2. The value J = I = 3.5 is specified for each resonance so that g = .5.

The unresolved parameters were obtained from averaging the resolved parameters. The unresolved region is specified in file 2 from 60 to 10^5 eV with the following parameters for each of the J = 3 and J = 4 states for L = 0:

$$\rho = c\sqrt{E} = kR = 3.2 \times 10^{-3} \sqrt{E}$$

$$D = 7.25 \text{ eV}$$

$$< \Gamma_n^{\,o} > = 1.27 \times 10^{-3} \text{ eV}$$

$$< \Gamma_\gamma > = .060 \text{ eV} .$$

The smooth cross sections in file 3 are specified to be zero through the resonance region E = 1.075 to 10^5 eV.

Fast Neutron Region

Fast-neutron values of σ_T are specified for 29 energy values from 10^5 to 2×10^7 eV in file 3. The values for E > 2.5 MeV are based on the measurements of Foster and Glasgow[9] and the lower energy values are guessed from systematics.

The fast capture cross section σ_γ is specified in file 3 from 10^5 to 2×10^7 eV based on the data shown in Ref 8. The extrapolated behavior falls off slightly faster than 1/v.

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71-LU-176 1033 BNW PRI.COMM.1967 JUN67 B.R.LEONARD.JR. AND K.B.STEWART

LUTETIUM-176

General Identification

MAT = 1033
ZA = 71176.0
AWR = 174.43 Ref 1 $\frac{175.94}{1.008665}$
I = 7
R = $.73 \times 10^{-12}$ cm Ref 2

Radioactive Decay

MT = 102 $Lu^{177} \rightarrow Hf^{177}$ $\lambda = 1.20 \times 10^{-6}$ sec^{-1} Ref 3

Introduction

The primary objective was to provide a set of evaluated data for low-energy neutrons since the primary interest in Lu-176 is in application as a neutron spectrum indicator. However, since new data were available on σ_T for fast neutrons for elemental lutetium we have included the same fast-neutron data for σ_T and σ_γ as is contained in the Lu^{175} ENDF/B file.

Cross Sections

Low Energy

Roberge and Sailor(4) have published the results of precision measurements which they made on σ_T from 0.02 to 0.25 eV for a sample enriched in Lu^{176}. Their data were used to derive very precise values of the parameters of the 0.142 eV resonance which dominates the thermal cross section of Lu^{176}. Their data apparently show that essentially all of the thermal cross section is due to this resonance. In the ENDF/B file we have used the parameters determined by Roberge plus the resonance parameters listed in file 2 to calculate the low energy cross sections of Lu^{176}. The calculations were performed by UNICORN(5) for a temperature of $0^{o}K$ with the center-of-mass term removed since laboratory energy coordinates were used. The results of this calculation are entered in

ENDF/B file 3 as 37 point values of σ_T(MT=1), σ_n(MT=2), and σ_γ(MT=102) from 10^{-4} to 0.88 eV. The results give the following values for a neutron energy of 0.0253 eV:

$$\sigma_T = 1955 \text{ barns}$$
$$\sigma_n = 3.04 \text{ barns}$$
$$\sigma_\gamma = 1952 \text{ barns}$$

There are other measurements of lutetium cross sections at low energies which are discrepant with the low energy cross sections given in the ENDF/B file. These other measurements imply a significant contribution at thermal energies from a bound level.

Atoji[2] measured a value of $\sigma_T = 105 \pm 2$ barns for elemental lutetium at an energy of 0.0735 eV. If this discrepancy were due to Lu^{176} it would require a value of $\sigma_T = 3430$ barns at 0.0735 eV. The precise measurements of Roberge give a value of about 2950 barns at this energy.

Amaral, et al[6] have measured the total cross section from 0.0185 to 0.203 eV with a crystal spectrometer. Although they obtained 0.142 eV resonance parameters that were sensibly the same as those of Roberge they report a value of $\sigma_T = 118 \pm 1$ barns at 0.0253 eV for elemental lutetium. Subtracting the Lu^{175} cross section from this value would leave a Lu^{176} cross section of 3500 barns. However, Baston[7] has made measurements on an enriched sample of Lu^{176} in this region with a time-of-flight spectrometer. Baston's resonance parameters again agree well with those of Roberge. Baston's data in the low energy region lie somewhat higher on the average than the values calculated from the resonance parameters but his average values in the region of 0.0253 eV are only about 2200 barns.

Thus it is concluded that the results of Roberge are the best estimate of the low energy cross sections of Lu^{176} at this time.

Resonance Region

A search of CINDA (1966)[8] shows no new information on the resonance parameters of Lu^{176}. Thus the values given in the 1960 supplement to BNL-325[9] have been incorporated in the ENDF/B file. The resolved resonance region extends from 0.8796 to 48 eV and contains 20 resonances. The value of J = I = 7.0 is specified to obtain g = 0.50.

The unresolved resonance region is specified from 48 eV to 100 keV. The average resonance parameters are assumed the same for each spin state and L = 0:

$$\rho = c\sqrt{E} = kR = 3.2 \times 10^{-3} \sqrt{E}$$

$$D = 4.66 \text{ eV}$$

$$< \Gamma_n^o > = 8.47 \times 10^{-4} \text{ eV}$$

$$< \Gamma_\gamma > = 0.060 \text{ eV}$$

The smooth cross sections in file 3 are specified to be zero throughout the resonance range 0.88 to 1 x 10^5 eV.

Fast-Neutron Range

Values of σ_T and σ_γ are specified in file 3. These are the same values given for Lu^{175} (MAT = 1032).

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73-TA-181	1126	AI	AI-AEC-12990(1971)	APR71	OTTER.DUNFORD.OTTEWITTE
73-TA-182	1127	AI	AI-AEC-12990(1971)	APR71	OTTER.DUNFORD.OTTEWITTE

Thermal Region

Experimental values of the total cross section for Ta^{181} below 1 ev are taken from Havens, Evans, Schmunk, and Adib. The total cross section at 0.0253 ev was evaluated to be 28 ± 3 barns. The evaluated capture cross section at 0.0253 ev of 21 ± 3 barns was taken from BNL-325. Cross sections calculated from the positive energy resonance parameters were σ_c = 16.3 barns and σ_t = 21.4 barns.

If the 0.0253-ev discrepancies were to be accounted for by adjustment of the 4.3-ev resonance capture width, the revised width would be improbably large and the total cross section too small. If the scattering width of the 4.3-ev resonance were revised, disagreement with the measured capture resonance integral would result. Thus, the discrepancies were attributed to negative energy resonances.

The parameters for a negative energy resonance were determined by fitting the evaluated capture and total 2200 m/s cross sections. Γ_γ was fixed at its average value and Γ_n and E_0 allowed to vary. The spin assignment made little difference when the variable parameters were independently optimized. The 2200 m/s cross sections calculated from all resonances are σ_c = 21.1 barns, σ_s = 6.2 barns, and σ_t = 27.3 barns. The scattering cross section is in good agreement with the value of 6 barns recommended by Hughes.

The only data for Ta^{182} is that of Stokes who gives a 2200 m/s total cross section of 8200 ± 600 barns. The value calculated from positive energy resolved resonances is 8215 barns. The other spin assignment for the 0.147-ev resonance would change this value by +20 barns. At 1 and 3 ev, which are near minima in the local cross section, the calculated total cross sections are about 30 barns less than the measured values. These calculated values are affected little by spin assignments. The presence of a negative energy level is thus indicated.

A negative energy level was created with Γ_γ chosen to be the average radiation width and the resonance energy, E_0 taken to be -20 ev, which is small enough to give an approximately 1/v capture cross section below 1 ev, i.e., $\left| E_0/2 \right| >> 1$. The neutron width was calculated to give σ_t = 29 barns at 1 ev. The calculated 2200 m/s cross sections are σ_c = 8249 barns, σ_s = 31 barns, and σ_t = 8280 barns. The choice of negative energy resonance parameters and spin assignments for resonances may vary the scattering cross section considerably. Below 0.4 ev it is estimated to be known only to about ±75%.

Resolved Resonance Region

Resolved resonance parameters derived from transmission measurements were evaluated for Ta^{181} and Ta^{182}. Missing values for radiation widths, Γ_γ, and compound nucleus spins, J, were supplied via theory. The set of resolved resonances was examined to determine: (1) the probable number of p-wave resonances which had been resolved and (2) the upper energy limit of resolution.

The potential scattering cross section was evaluated. Cross sections at thermal energies were calculated from the selected parameters and compared to measured values. Since the calculated thermal cross sections were smaller than measured values, parameters were determined for a negative energy resonance which would supply the additional thermal cross section contributions necessary to match the evaluation of measured values.

All resolved resonances in the evaluated set are assumed to be for s-wave (ℓ = 0) neutrons. All suspected p-wave resonances were eliminated. The p-wave contributions in the resolved resonance range have been given as smooth background. However, the unresolved resonance parameters may be used to generate the p-wave contributions, and thus allow for resonance self-shielding. By eliminating p-wave resolved resonances and supplying all the p-wave cross sections from unresolved parameters (or smooth cross sections), it is more certain that the p-wave cross section is adequately represented.

Values of E_0, $2g\Gamma_n$, and Γ_γ are taken from BNL-325 for Ta^{181}. The value of $2g\Gamma_n$ for the 55.8-ev resonance was corrected to 0.2 mv.

Measured values of J for Ta^{181} are taken from Wasson 1969. J values are known for the 4.3, 10.3, 14.0, and 23.9 ev resonances. The resonances at 35.1 and 35.9 ev have been determined to have different J values. J = 3 was assigned to the 35.1-ev resonance and J = 4 to the 35.9-ev resonance.

Values of E_0, $2g\Gamma_n$, and Γ_γ derived from measurements on Ta^{182} are taken from Stokes, which is the only data available. No measured values of J have been reported.

Ta^{181} and Ta^{182} have spin $I \neq 0$ so that two values of compound nucleus spin $J = I \pm 1/2$ are possible. For many resonances of the tantalum isotopes these values have not been established experimentally. Often resonances with unknown J values are assigned $J = I$ to form a third group. This approach may lead to serious errors when calculating thermal scattering cross sections, because interference between resonance and potential scattering is usually important in this calculation. The interference takes place between the potential scattering amplitude and the total resonance scattering amplitude of each set of resonances having a particular J value. Thus, if a third set of resonances is formed (whether or not they are allowed to interfere with potential scattering), the calculation will be in error.

The procedure used in this evaluation was to assign a possible J value to each resonance so that the potential scattering interferes with more nearly correct resonance scattering terms. The J values were assigned in proportion to $(2J + 1)$ as given by theory. (This division is less sophisticated than that used for determining the unresolved resonance level spacings, but appears to be adequate for this purpose.)

The value of Γ_n was changed to preserve the experimentally determined values of $2g\Gamma_n$ in all cases except for the three lowest energy resonances of Ta^{182}. For these, the peak cross section $\propto (g\Gamma_n/\Gamma)$ was preserved because shape analysis, rather than area analysis, had been used to derive their parameters. The total width is nearly preserved in these cases because $\Gamma_n >> \Gamma$.

For resonances with unknown radiation widths, an average value of Γ_γ was used. The arithmetic average of the 26 resolved values for Ta^{181}, 56 mv, was used. This value is lower than that obtained for the unresolved resonance range. The capture resonance integral calculated using 56 mv for the unknown resonances is in good agreement with the evaluated value. The capture width of Ta^{182} is reported for only three resonances. The value of 67 mv found for all three was used for the other resolved resonances.

For Ta^{182}, no resonances of very small width were resolved, so all resolved resonances were assumed to be s-wave resonances.

For Ta^{181}, the upper end of the linear region coincides with the energy below which all observed s-wave resonances have resolved values of Γ_n. This occurs about 330 ev, and the limit is taken there. For Ta^{182}, the small number of resonances resolved and the obscuring of energy regions by resonances of other isotopes in the measured samples make the above analysis inapplicable. The resolved range was set to include all resonances with resolved values of Γ_n. Unfortunately, a large resonance exists at 34.7 ev, just above the resolved range.

Potential Scattering Cross Section

Seth determined the potential scattering cross section of natural tantalum to be 8.5 ± 0.8 barns by subtracting calculated resonance contributions from measured total cross sections in the low energy resolved resonance range, and by transmission analysis in the kev range. The total cross section at 100 kev, using the latter value, is about 0.2 barn higher than the evaluated experimental cross section of 9.0 ± 0.9 barns. The comparison at 100 kev is a good test because potential scattering contributes over 80% of the total cross section, which is known to be ±10%. The value of 8.3 ± 0.8 barns was adopted for both tantalum isotopes. This value fits well an interpolation of measured potential scattering cross sections vs atomic mass near A = 180.

Unresolved Resonance Region

The unresolved resonance parameters were determined by a combination of theoretical assumptions and fits to evaluated measured cross sections. Theory had to be invoked to limit the number of independent variables, because the accuracy of the measured cross sections was only sufficient to determine a few variables unambiguously.

Two types of fits were made. For the convenience of those without computer codes which accommodate energy-dependent parameters, a fit with energy-independent parameters was given for the ENDF/B.

The following assumptions were made for the energy-independent fit:

1) The radiation level width is independent of energy, neutron angular momentum ℓ, and compound nucleus spin J.

2) The strength functions,

$$S_{\ell,J} = \frac{\langle \Gamma_n^{\ 0} \rangle_{\ell,J}}{\langle D \rangle_{\ell,J}} ,$$

are independent of J and energy E.

3) The average level spacing $\langle D \rangle_{\ell,J}$ is independent of ℓ and energy, and its J dependence is given by the formula of Cook; namely,

$$\langle D \rangle_J \propto (2J + 1)^{-1} \exp\left[- \frac{\left(J + \frac{1}{2}\right)^2}{2\sigma^2} \right] ,$$

where σ is a constant for each isotope.

4) Elastic scattering with a change of ℓ value and inelastic scattering are neglected. This assumption is necessary because the ENDF/B format does not allow for these processes explicitly.

5) Doubly occurring (ℓ,J) series were assumed to be single series with two degrees of freedom rather than two competing series, each with one degree of freedom. The former is easier to accommodate in the current ENDF/B format and the practical difference is negligible.

A second, more accurate fit was made without invoking assumption 4 above, and with the energy dependence of $\langle D \rangle_{\ell,J}$ given by Cook et al. The strength functions for inelastic scattering were assumed to be the same as for elastic scattering.

Smooth background cross sections were supplied (ENDF/B File 3) to match evaluated results for both the energy-dependent and energy-independent fits.

The radius "a" of the centrifugal potential well used to calculate angular momentum barrier penetration probabilities for neutrons with non-zero angular momenta was taken equal to $[1.23(A/M_n)^{1/3} + 0.8]$ fermis as required by ENDF/B.

The calculation of average cross sections from resonance parameters involves averaging over the distributions of reaction level widths. This is often done by combining a "fluctuation integral" $R_{i_{\ell,J}}$ with cross sections calculated from average widths.

$$R_{i_{\ell,J}} = \frac{\left\langle \Gamma_n \Gamma_i \right\rangle_{\ell,J}}{\left(\dfrac{\overline{\Gamma}_{n_{\ell,J}} \overline{\Gamma}_{i_{\ell,J}}}{\overline{\Gamma}_{\ell,J}} \right)}$$

In calculating $R_{i_{\ell,J}}$, a χ^2 distribution with $\mu_{i_{\ell,J}}$ degrees of freedom is assumed. In addition, $\mu_{n_{\ell,J}}$ is used to obtain $\overline{\Gamma}_{n_{\ell,J}}$ from the input $\overline{\Gamma}^0_{n_{\ell,J}}$:

$$\overline{\Gamma}_{n_{\ell,J}} = \overline{\Gamma}_{n_{\ell,J}} \mu_{n_{\ell,J}} \nu_\ell \sqrt{E}$$

where ν_ℓ is the angular momentum barrier penetration factor and the radiative width $\Gamma_{\gamma_{\ell,J}}$ is assumed constant.

The remaining independent variables include the potential scattering cross section, σ_{pot}, the average radiation width $\langle\Gamma_\gamma\rangle$, the strength functions, and $\langle D\rangle_{\ell,J}$ for one (ℓ,J) series. In practice, the $\ell = 0$ level spacing, $\langle D\rangle_{\ell=0}$, was used.

The unresolved resonance parameters were ultimately determined by minimizing the goodness-of-fit between calculated and evaluated (described later) capture cross sections. The uncertainty in evaluated cross sections was assumed to be independent of energy.

Energy Range for Unresolved Resonances Region

Very large lumps of tantalum have been proposed for reflector poison-backings of compact reactors and control rods of fast breeder reactors. The combination of the high importance at high energies and the large lump sizes cause resonance self-shielding to have significant reactivity effects at unusually high energies. Consequently, the upper limit of the unresolved energy range has been set at 100 kev for Ta^{181}. For high temperatures this may be unnecessarily high because of overlapping of resonances due to Doppler broadening. However, it is easier to transform resonance parameters into smooth cross sections than vice versa.

Ta^{182} is almost always combined with Ta^{181}, but is normally present at low concentrations. Self-shielding for Ta^{182} is a factor only at low energy where the optical dimension is significant. For this reason the unresolved resonance high energy limit has been set at 10 kev. Smooth cross sections generated from resonance parameters have been supplied from 10 to 100 kev.

s-, p-, and d-wave neutrons contribute significantly to reaction rates over different restricted energy ranges. p-wave contributions to capture are less than 0.2% of the total below 330 ev, and d-wave contributions less than 0.1% below 10 kev. Two energy ranges were made for unresolved resonances in Ta^{181}. From 330 ev to 10 kev, only s- and p-wave contributions were calculated and from 10 to 100 kev, s-, p-, and d-wave contributions were all calculated. Since the upper energy limit of the unresolved range for Ta^{182} is 10 kev, no d-wave calculation was made, and a single unresolved energy range was used, namely, 35 ev to 10 kev.

In general, since the resolved resonance range contains only s-wave resonances, some contribution from unresolved p-wave resonances is called for. However, as noted previously, these contributions are negligible for tantalum.

Average Parameters Derived From Resolved Resonances

Ta^{181}

The s-wave strength function determined from the resolved resonance data is $S_0 = (1.8 \pm 0.4) \times 10^{-4}$, $\langle \Gamma_\gamma \rangle = 56 \pm 2$ mv, and $\langle D \rangle_{\ell=0} = 4.4 \pm 0.5$ ev. $\langle \Gamma_\gamma \rangle$ was obtained by an unweighted average of the 26 measured values. The distribution of values conformed closely to a normal distribution and was unusually narrow.

Ta^{182}

The s-wave strength function of 1.0×10^{-4} is based upon 8 resonances and is thus not very helpful. It is apparent from the data of Stokes that the value is considerably larger in the region adjacent to the resolved resonance range. All three measured values of Γ_γ are the same, 67 mv, with $\langle D \rangle_{\ell=0} = 3.5 \pm 1.2$ ev. Since a good test against measured cross sections was not possible, $\langle \Gamma_\gamma \rangle = 67$ mv and $\langle D \rangle_{\ell=0} = 3.5$ ev were adopted for the unresolved resonance range.

Comparison of Calculated and Measured Resonance Integrals

Ta^{181}

The capture resonance integral calculated from the evaluated resonance parameters plus smooth cross sections is 738.7 barns. This agrees well with a recent evaluation of measurements by Drake which gave 740 ± 40 barns. A breakdown of the calculated result by component is given in the following table.

INFINITELY DILUTE RESONANCE INTEGRAL
FOR CAPTURE IN Ta^{181}

Description	Component of Integral (barns)
Resolved Resonances (0.5 to 330 ev)	
Negative energy resonance	1.37
4.28 ev resonance	465.55
Other 74 resonances	243.52
Unresolved Resonances (330 to 10^5 ev)	
ℓ = resonances	26.88
$\ell = 1$	0.86
$\ell = 2$	0.01
Smooth Cross Section	0.47
Total	738.66

Ta^{182}

The capture resonance integral calculated from the evaluated resonance parameters is 1020 barns. A breakdown by component is given below. No measured values have been found in the open literature for comparison. The resonance integral of 943 ± 50 barns deduced by Stokes is in reasonable agreement with our value.

INFINITELY DILUTE RESONANCE INTEGRAL
FOR CAPTURE IN Ta^{182}

Description	Component of Integral (barns)
Resolved Resonances (0.5 to 35 ev)	12.7
Negative energy resonance	12.7
0.147 ev resonance	715.2
Other 8 resonances	154.1
Unresolved Resonances (35 to 10^5 ev)	
$\ell = 0$ resonances	137.0
$\ell = 1$	0.8
$\ell = 2$	0.0
Total	1019.8

EVALUATION OF CROSS SECTION DATA ABOVE 100 kev

A complete set of neutron cross sections was calculated for each isotope in the energy range between 100 kev and 17 Mev. The calculations were carried out on an energy grid which was fine enough to provide an adequate shape description of the various reaction cross sections. A deformed optical model was used to describe the total cross section and all direct processes. A statistical model of the compound nucleus was used to separate the compound nucleus formation cross section into its constituent parts.

Radiative Capture Cross Sections

Above 100 kev smooth cross sections were specified for the tantalum isotopes in ENDF/B File 3. In the case of Ta^{182}, these data were derived entirely from theory. Arguments for the choice of capture cross section in the neighborhood of 100 kev are given in AI-AEC-12990. From 100 to 140 kev a visual fit was made from the data of Kompe, Brzosko, and Miskel. The capture data of Fricke tend to remain high in this energy range. Upon renormalization, the data of Macklin and Biggons, and Kononov support the evaluation made in this energy range. From 140 to about 240 kev the numerous experiments were found to be in good agreement. From 240 kev up to 2 Mev we relied upon the data of Fricke, Brzosko, and Cox which were in close agreement. Limited guidance was provided by the somewhat oscillatory data of Miskel in this energy range.

Above 2 Mev, considerable uncertainty exists regarding the capture cross section, as it rapidly approaches zero. In this region, the data of Miskel were used in preference to those of Kompe as the former agree better with the shape of our theoretical calculations:

Above 5 Mev, no data exist for the capture cross section. The theory of Benzi and Reffo was utilized to describe the collective and direct interaction capture cross sections to 17 Mev. For these calculations, the nuclear deformation, β, was taken to be 0.265 for both isotopes. The nuclear radius, R, was taken to be 1.2 $A^{1/3}$ fermis. Credibility of these calculations is reasonable based upon agreement with the measurement available in the neighboring nucleus, W^{186}, at 14.5 Mev.

Total Cross Section

Total cross sections were specified for the tantalum isotopes in ENDF/B File 3. Again, in the case of Ta^{182}, these data were derived entirely from the results of the 2-PLUS and COMNUC computer runs.

The total cross section for Ta^{181} just above 100 kev was established from the 1949 University of Wisconsin measurements of Bockelman and the time-of-flight data of A. B. Smith. Bockelman's measurements were done at 0 and at 115°. Above 250 kev, the measurements at 115° deviated markedly from those at 0° and were ignored. Data were received from Divadeenam at Duke University (1970) which revised the 1965 Duke measurements in the energy range above 100 kev. Smith's data and the newer Duke measurements agree quite well up to their maximum energies of 650 kev. From 700 kev to 1 Mev, the 1967 RPI measurements of Martin were relied upon.

Elastic Cross Sections and Angular Distributions of Elastically Scattered Neutrons

The elastic data is specified in ENDF/B File 3, while the angular distributions are specified in File 4. Theory was used for the Ta^{182} file.

Little experimental data are available for the Ta^{181} elastic cross section. Below 100 kev there apparently is none available. Above 100 kev there are essentially two large sets of data and six single-energy experiments, the references for which may be found in CINDA.

The two large sets of data are those of Smith and Holmqvist. The theoretical cross sections generated in this study consisted of shape elastic scattering obtained from 2-PLUS and compound elastic scattering obtained obtained from the COMNUC code. Comparison of these calculations to Holmqvist's data and to most of the single-energy experimental points show good agreement.

Comparison to the experimental points of Smith shows relatively poor agreement. Two observations regarding the Smith data must be noted, however. First Smith measured total, elastic, and inelastic cross sections. The sum of the elastic and inelastic measurements is considerably greater than the total measurement. This occurs over most of the range measured (300 kev to 1.5 Mev). Secondly, the sum of our calculated elastic cross section plus the partial cross section exciting the 136-kev level gives excellent agreement with Smith's quoted elastic cross section. This suggests that Smith was unable to completely resolve the 136-kev excitation from the elastic cross section. Indeed they show only a single data curve for the doublet centered at 144 kev, and indicate that the excitation of the lower energy state of the pair was roughly 1.6 times more intense than that of the higher energy state.

The Ta^{181} theoretical calculations of the elastic cross section were adopted with the following changes: small increases were made in the elastic cross section corresponding to adjustments made in the total cross section, and minor changes were also made to the elastic cross section corresponding to differences between the evaluated radiative capture cross section and COMNUC results above 100 kev.

These modifications produce an evaluated elastic cross section which is in good agreement with those of Holmqvist and most of the single-energy-point experimental data.

Theoretical values of the angular distribution of elastically scattered neutrons for the tantalum isotopes were obtained from the 2-PLUS and COMNUC calculations. Legendre coefficient data was printed out directly. The derived quantities, $\bar{\mu}_{lab}$, ξ, and γ were calculated from the angular distributions using the CHAD code.

The angular distributions were assumed isotropic in the center-of-mass system from thermal energies to 10 kev. Linear interpolation of the Legendre coefficients was assumed between 10 and 100 kev.

Inelastic Cross Section and Angular Distributions of Inelastically Scattered Neutrons

No experimental data were available for the evaluation of Ta^{182}. A few sets of experimental data were available for evaluation of the Ta^{181} partial excitation functions. The most extensive were those of Smith and the MIT measurements of Rogers et al. None of the available data was adequate to define a suitable set of partial inelastic excitation functions. Consequently, comparison of theory and measurement was of limited value. In general, where comparison was possible, the agreement was reasonable. This generally meant adding up the theoretical excitation functions for several levels to compare to one "experimental average" excitation function.

Comparison was made, however, between calculation and the measured Ta^{181} total inelastic cross section. Summed partial excitation data to 1.5 Mev showed reasonable agreement within the band of fluctuations. Above 5 Mev, the data of Owens, Rosen, and Thomson, substantiate the theoretical calculations which formed a basis for the evaluated cross sections.

In the case of Ta^{182}, the cross sections for exciting individual levels calculated with COMNUC were adopted, with minor changes at energies near the threshold of 0.0975 Mev. Structure in the 97-kev level cross sections calculated by COMNUC near the threshold was smoothed out. Similar structure calculated for the 2nd level (114 kev) was also smoothed out near threshold. The smoothing procedure was constrained by the total inelastic cross section. The structure was believed to be caused by competition for open channels due to the fact that the 1st level is weakly coupled and the 2nd level strongly coupled to the ground state.

Below 3 Mev, the theoretical calculations included 9 levels (Ta^{181}), or 8 levels (Ta^{182}) plus a continuum. The continuum represents both the $(n,\gamma n)$ process and the $(n,n\gamma)$ excitation above the 9th (or 8th) level. The $(n,\gamma n)$ process involves a photon cascade and could not be allocated to a specific energy level.

Discrete level angular distributions were specified in ENDF/B File 4. Very limited experimental data exist for differential inelastic scattering. The little data observed offer no opposition to the decision to make all level distributions isotropic in the center-of-mass frame for both isotopes. The continuum was made isotropic in the lab frame.

Cross Sections for the (n,2n) and (n,3n) Reaction

The thresholds for the (n,2n) and (n,3n) reaction were obtained from Mattauch et al. For Ta^{181}, the thresholds are at 7.68 and 14.49 Mev, respectively. The Ta^{182} thresholds are lower; at 6.10 and 13.79 Mev, respectively. The only experimental data available were for the Ta^{181} (n,2n) Ta^{180} reaction. These are referenced in CINDA.

Since no experimental data were available for the (n,3n) reaction, the adopted cross sections for both isotopes were obtained by simply subtracting the (n,2n) and inelastic continuum from the remaining nonelastic cross sections.

Cross Sections for the (n, α) Reaction

To obtain the cross section set for ENDF/B, the compound nucleus reactions and the direct interaction measurements were added to form the total (n, α) + (n,nα) cross section. The same cross sections were used for the Ta^{182} file.

Cross Sections for the (n,p) Reaction

The (n,p) cross section, being small and not well known, was not put in the ENDF/B data file.

Secondary Neutron Energy Distributions

The ENDF/B File 5 contains data for the energy distributions of secondary neutrons. These distributions are expressed as normalized probability distributions,

$$P(E \rightarrow E') = \sum_{k=1}^{NK} P_k(E) f_k(E \rightarrow E') \quad ,$$

where $P_k(E)$ is the fractional probability that the distribution $f_k(E \rightarrow E')$ is used at incident energy, E.

The partial energy distribution for tantalum has been specified by a Maxwellian evaporation spectrum

$$f(E \rightarrow E') = \frac{E'}{I} e^{-E'/\theta} \quad .$$

I is the normalization constant and θ is the incident energy dependent nuclear temperature.

Data presented by Owens and Towle, Tsukada et al, and Buccino et al indicate that the nuclear temperatures can be expressed adequately as a function of excitation energy, E^*, by the expression:

$$\theta(E) = \left(\frac{E^*}{a}\right)^{1/2}$$

where

$E^* = E_{inc} - E_{th}$

E_{inc} = incident neutron energy

E_{th} = threshold energy for the inelastic process

= 137 kev for Ta^{181}.

This formulation was used for the continuum inelastic neutrons. The level density parameter, a, was evaluated from the reference data. The value a = 17.4 fits Ta^{181} adequately over most of the continuum energy range and was used for Ta^{182}.

For the (n,2n) reaction the energy distribution of the emitted neutrons was specified by a mixture of Maxwellian evaporation spectra. Here $P_1(E) = P_2(E) = 1/2$ for all incident neutron energies. The characteristic nuclear temperature of the first emitted neutron, θ_1, was assumed to be the same as that prescribed for the inelastic continuum process above. θ_2 was approximated from above with $E_2^* = E - 2\theta_1 - E_b$. Here E_2^* is the excitation energy of the residual nucleus following emission of the second neutron, $2\theta_1$ is the average kinetic energy of the first emitted neutron, and E_b is the binding energy of the second emitted neutron (7.68 Mev for Ta^{181}, 6.10 Mev for Ta^{182}).

The approximation is not valid for energies $-2\theta < E^* < 0$. Here the nuclear temperatures were held at a constant value, somewhat lower than the calculated in the transition energy range.

A similar evaluation was used for the (n,3n) reaction. θ_3 was evaluated with $P_k(E) = 1/3$ and the excitation energy, $E^*_3 = E - E_b - 2\theta_1 - 2\theta_2$. For this reaction, $E_b = 14.49$ Mev for Ta^{181} and 13.79 Mev for Ta^{182}.

74-W-182 1060 GE-NMPO GEMP-448 (NOV 66) NOV66 A.PRINCE.W.B.HENDERSON ET.AL.

ENDF/B MATERIAL NO= 1060
W-182 GE(NMPO) EVAL-NOV66 A.PRINCE + W.B.HENDERSON, ET AL
GEMP-448(NOV.1966) DIST-JUL68 REV-JUN70
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DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
* * * * * * *
TUNGSTEN-182,GE-NMPO,OCTOBER 30,1966
EVALUATED PRIMARILY BY A.PRINCE,FORMERLY AT GE-NMPO,NOW AT BNL.
UNRESOLVED RESONANCE PARAMETERS AND SMOOTH CAPTURE EVALUATED BY
W.B.HENDERSON,GE-NMPO

----RESOLVED RESONANCE PARAMETERS----

1) 5 LEVELS,PRIVATE COMMUNICATION,J.R.STEHN,FEB.26,1964
2) GAMMA SUB GAMMA=0.057EV WAS ASSUMED FOR 213EV AND NEG. LEVEL.
3) NEG. ENERGY LEVEL AT -0.7EV WITH GAMMA SUB N=1.41E-5 AND SCATTER LENGTH OF 8.5E-13 CHOSEN TO FIT DATA OF FRIESENHAHN ET AL.NASA CR- GA-6832.
4) RESULTING SCATTER AND ABSORPTION SIGMAS AT 0.0253EV ARE 4.22 AND 21.59B.

----UNRESOLVED RESONANCE PARAMETERS----

1) REDUCED NEUTRON WIDTH AND LEVEL SPACING FOR L=0 FROM EVALUATION BY BLOCK ET AL,ORNL-3924,MAY 1966,P.31,S0=2.905E-4.
2) REDUCED WIDTH FOR L=1 BASED ON BEST FIT TO EVALUATED CAPTURE DATA (C41) FOR NATURAL TUNGSTEN FROM 10KEV TO 100KEV.RESULTING P AND D STRENGTH FUNCTIONS ARE S1=0.35*S0 AND S2=0.75*S0. ASSUMING PROCESSING CODE WILL USE ONLY L=0 AND L=1,SMOOTH FILE 3 COMPENSATES.GAMMA SUB GAMMA=0.070EV FOR ALL STATES.
3) RANGE IS 281EV TO 100 KEV.SCATTER LENGTH IS 7.2E-13.
4) LARGE LEVEL SPACING MAKES UNRESOLVED AVERAGE SIGMAS SUSPECT AT LOWER ENERGIES,HOWEVER NO CORRECTION HAS BEEN ATTEMPTED SINCE RESOLVED PARAMETERS TO 1170EV (C17) ARE AVAILABLE AND WILL BE INCLUDED IN FIRST UPDATING

----SMOOTH CROSS SECTIONS,ANGLE,AND ENERGY DISTRIBUTIONS----

1) PRIMARILY FROM ABACUS-2 CALCULATIONS AND MODIFICATIONS THERETO BY A.PRINCE,GEMP-388,NOV.12,1965.MODIFICATIONS DESCRIBED BELOW
2) BELOW 0.55MEV THE ABACUS ELASTIC SIGMA WAS REDUCED TO MATCH WITH UNRESOLVED CALC. AT 0.1MEV.ALSO THE INELASTIC SIGMA FOR FIRST EXCITED STATE WAS TAKEN FROM 2-PLUS CALC. BY DUNFORD, NAA-SR-11973,JULY 15,1966.BOTH CHANGES REDUCE SCATTER AND TOTAL SIGMAS AT LOWER ENERGIES.AND AGREEMENT WITH NAT.W DATA (ANL-5567 AND A.B. SMITH,PRIVATE COMM.) IS IMPROVED.
3) ENERGY,SPIN,AND PARITY OF GROUND STATE AND 15 EXCITED LEVELS TAKEN FROM NRC NUCLEAR DATA SHEETS AND KONDRAT EV,JETP 19,1964 P.1513.
4) RADIATIVE CAPTURE IS BASED ON EVALUATION OF NATURAL TUNGSTEN BY TROUBETZKOY ET AL.UNC-5099,DEC.31,1964,WHICH PRODUCES GOOD REACTIVITY WORTH CORRELATION IN 710 FAST SPECTRUM CRITICAL. SPLIT AMONG ISOTOPES IS BASED ON UNRESOLVED RESONANCE CALC.
5) FROM 2.0MEV TO 8.0MEV ABACUS RESULTS WERE USED,BUT SINCE LEVEL DATA ARE INCOMPLETE,NO INDIVIDUAL LEVEL DATA WERE USED AND INELASTIC NEUTRON ENERGY DISTRIBUTION IS MAXWELLIAN WITH THETA=SQRT(E/A),WHERE SMALLA IS 25MEV-1 BASED ON DATA OF D.B. THOMPSON,PHYS.REV.129,1963,P.649.
6) AN EMPIRICAL SIGMA N,2N CURVE WAS DRAWN ABOVE THRESHOLD,8.03 MEV,AS FOR TA-181,MAT=1035.ABOVE N,2N THRESHOLD THE ABACUS REACTION CROSS SECTION WAS EXTRAPOLATED FOLLOWING NON-ELASTIC TREND IN BNL-325,2ND ED.,JULY 1,1958.SHAPE ELASTIC WAS TAKEN AS ABACUS TOTAL MINUS EXTRAPOLATED REACTION SIGMA.
7) OPTICAL MODEL PARAMETERS WERE FROM WILMORE AND HODGSON,NUCL. PHYS.55,1964,P.673 AS GIVEN FOR TA-181,MAT=1035.

8) SIGMA N,P FOLLOWS EVALUATION OF TROUBETZKOY ET AL (C41) AND
   DATA QUOTED BY CHATTERJEE,NUCLEONICS 23,NO,8,1965,P,112,
9) SHAPE OF DIFFERENTIAL ELASTIC SIGMA ABOVE 4,1MEV ASSUMED SAME
   AS ABACUS RESULTS FOR W=184,MAT=1062
   ---THE ABSORPTION INTEGRAL ABOVE Ø,5EV IS 595B,----
   ---DECAY DATA FROM D,T,GOLDMAN,CHART OF THE NUCLIDES,8TH ED,

74-W-183 1061 GE-NMPO GEMP-448 (NOV 66) NOV66 A.PRINCE.W.B.HENDERSON ET.AL.

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                    ENDF/B MATERIAL NO= 1061
W-183       GE(NMPO)    EVAL=NOV66 A.PRINCE + W.B.HENDERSON ET AL
GEMP-448 (NOV,1966)  DIST=JUL68 REV-JAN72
*        *        *        *        *        *        *
DATA MODIFIED JAN, 1972
LOW ENERGY RADIATIVE CAPTURE MODIFIED TO CONFORM TO THE CSEWG
NORMALIZATION AND STANDARDS SUBCOMMITTEE RECOMMENDED VALUE OF
10.2 BARNS FOR THE 2200 M/SEC CROSS SECTION
*        *        *        *        *        *        *
DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
*        *        *        *        *        *        *
TUNGSTEN-183,GE-NMPO,OCTOBER 30,1966
EVALUATED PRIMARILY BY A.PRINCE,FORMERLY AT GE=NMPO,NOW AT BNL.
UNRESOLVED RESONANCE PARAMETERS AND SMOOTH CAPTURE EVALUATED BY
W.B.HENDERSON,GE-NMPO
              ----RESOLVED RESONANCE PARAMETERS----
1) 15 LEVELS,PRIVATE COMMUNICATION,J.R.STEHN,FEB,26,1964
2) NEG.ENERGY LEVEL AT -6.0EV WITH GAMMA SUB N=4.104E-4 AND GAMMA
   SUB GAMMA=0.070EV WERE CHOSEN TO FIT DATA OF FRIESENHAHN ET AL
   NASA CR- GA-6832, SCATTER LENGTH=8.5E-13
3) RESULTING SCATTER AND ABSORPTION SIGMAS AT 0.0253EV ARE
   4.54 AND 9.60B.
            UNRESOLVED RESONANCE PARAMETERS----
1) REDUCED NEUTRON WIDTH AND LEVEL SPACING FOR L=0 FROM EVALU=
   ATION BY BLOCK ET AL,ORNL-3924,MAY 1966,P.31,S0=2.000E-4.
2) REDUCED WIDTH FOR L=1 BASED ON BEST FIT TO EVALUATED CAPTURE
   DATA FOR NATURAL TUNGSTEN FROM 10KEV TO 100KEV,INCLUDING
   COMPETITION WITH THE INELASTIC LEVEL AT 46.5KEV AND L=2 CON=
   TRIBUTION,RESULTING P AND D STRENGTH FUNCTIONS WERE OBTAINED
   USING SAME RATIOS AS FOR THE EVEN A ISOTOPES,S1=0.35*S0 AND
   S2=0.75*S0,ASSUMING PROCESSING CODE WILL USE ONLY L=0 AND L=1
   AND WILL IGNORE INELASTIC COMPETITION,SMOOTH FILE 3 COMPEN=
   SATES,GAMMA SUB GAMMA=0.080EV FOR ALL STATES WAS USED (C16).
3) RANGE IS 257EV TO 120KEV,SCATTER LENGTH IS 7.2E-13,
4) LARGE LEVEL SPACING MAKES UNRESOLVED AVERAGE SIGMAS SUSPECT AT
   LOWER ENERGIES,HOWEVER NO CORRECTION HAS BEEN ATTEMPTED.
   RESOLVED PARAMETERS TO 392EV (C16) ARE AVAILABLE FOR INCLUSION
   AT FIRST UPDATING.
----SMOOTH CROSS SECTIONS,ANGLE,AND ENERGY DISTRIBUTIONS----
1) SAME REMARKS AS FOR W-182,MAT=1060,APPLY EXCEPT AS NOTED BELOW
2) ALL INELASTIC LEVEL SIGMAS ARE FROM ABACUS-2,
3) ENERGY,SPIN,AND PARITY OF GROUND STATE AND 10 EXCITED LEVELS
   TAKEN FROM NRC NUCLEAR DATA SHEETS AND HEMATZ,PHYS,REV,128,
   1962,P.1186
6) N,2N THRESHOLD IS 6.23MEV.
9) ALL DIFFERENTIAL ELASTIC SIGMAS WERE TAKEN FROM ABACUS CALC.
   ----THE ABSORPTION INTEGRAL ABOVE 0.5EV IS 370 BARNS----
   ----DECAY DATA FROM GOLDMAN,CHART OF THE NUCLIDES,8TH ED.----
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74-W-184 1062 GE-NMPO GEMP-448 (NOV 66) NOV66 A.PRINCE.W.B.HENDERSON ET.AL.

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                    ENDF/B MATERIAL NO= 1062
W-184      GE(NMPO)   EVAL=NOV66 A.PRINCE(BNL) + W.B.HENDERSON
GEMP-448 (NOV,1966)  DIST=JUL68 REV-JAN72
*        *          *          *          *          *          *
DATA MODIFIED JAN, 1972
THE LOW ENERGY RADIATIVE CAPTURE HAS BEEN CHANGE TO CONFORM TO
THE CSEWG NORMALIZATION SUBCOMMITTEE RECOMMENDED VALUE OF
1.80 BARNS FOR THE 2200 M/SEC CROSS SECTION
*        *          *          *          *          *          *
DATA MODIFIED JUNE,1972 TO CONFORM TO ENDF/B-II FORMATS
*        *          *          *          *          *          *
TUNGSTEN-184,GE-NMPO,OCTOBER 30,1966
EVALUATED PRIMARILY BY A.PRINCE,FORMERLY AT GE-NMPO,NOW AT BNL.
UNRESOLVED RESONANCE PARAMETERS AND SMOOTH CAPTURE EVALUATED BY
W.B.HENDERSON,GE-NMPO
               ---RESOLVED RESONANCE PARAMETERS---
1) 16 LEVELS,PRIVATE COMMUNICATION,J.R.STEHN,FEB.26,1964
2) GAMMA SUB GAMMA=0.057EV WAS ASSUMED FOR LEVELS AT 685EV AND UP
   AS WELL AS NEG. LEVEL.
3) NEG. ENERGY LEVEL AT -110EV WITH GAMMA SUB N=.50772EV AND
   SCATTER LENGTH OF 8.5E-13 CHOSEN TO FIT DATA OF FRIESENHAHN ET
   AL,NASA CR- GA-6832.
4) RESULTING SCATTER AND ABSORPTION SIGMAS AT 0.0253EV ARE
   6.57 AND 1.658.
            ----UNRESOLVED RESONANCE PARAMETERS----
1) REDUCED NEUTRON WIDTH AND LEVEL SPACING FOR L=0 FROM EVALU-
   ATION BY BLOCK ET AL,ORNL-3924,MAY 1966,P.31,S0=2.60E-4.
2) REDUCED WIDTH FOR L=1-SAME REMARKS AS FOR W-182,MAT=1060,APPLY
3) RANGE IS 2140EV TO 100KEV,SCATTER LENGTH IS 7.2E-13.
----SMOOTH CROSS SECTIONS,ANGLE,AND ENERGY DISTRIBUTIONS----
1) SAME REMARKS AS FOR W-182,MAT=1060,APPLY EXCEPT AS NOTED BELOW
3) ENERGY,SPIN,AND PARITY OF GROUND STATE AND 7 EXCITED LEVELS
   TAKEN FROM NRC NUCLEAR DATA SHEETS.
6) N,2N THRESHOLD IS 7.46MEV.
9) ALL DIFFERENTIAL ELASTIC SIGMAS WERE TAKEN FROM ABACUS CALC.
   -----THE ABSORPTION INTERGRAL ABOVE 0.5EV IS 12.48.-----
   -----DECAY DATA FROM GOLDMAN,CHART OF NUCLIDES,8TH ED.----
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74-W-186 1063 GE-NMPO GEMP-448 (NOV 66) NOV66 A.PRINCE.W.B.HENDERSON ET.AL.

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                     ENDF/B MATERIAL NO= 1063
W-186     GE(NMPØ)   EVAL=NOV66 A.PRINCE(BNL)+W.B.HENDERSON ET AL
GEMP-448 (NOV,1966)  DIST=JUL68 REV-JUN7Ø
*        *          *         *         *         *          *
DATA MODIFIED JUNE,197Ø TO CONFORM TO ENDF/B-II FORMATS
*        *          *         *         *         *          *
TUNGSTEN-186,GE-NMPO,OCTOBER 3Ø,1966
EVALUATED PRIMARILY BY A,PRINCE,FORMERLY AT GE=NMPO,NOW AT BNL,
UNRESOLVED RESONANCE PARAMETERS AND SMOOTH CAPTURE EVALUATED BY
W,B.HENDERSON,GE-NMPO
              ----RESOLVED RESONANCE PARAMETERS----
1) 4 LEVELS,PRIVATE COMMUNICATION,J,R,STEHN,FEB,26,1964
2) GAMMA SUB GAMMA=Ø,Ø62 ASSUMED FOR 22ØEV ,Ø,Ø6Ø FOR NEG, LEVEL,
3) FIT TO DATA OF FRIESENHAHN ET AL.,NASA CR- GA-6832 REQUIRES
   NEUTRON AND GAMMA WIDTHS FOR 18,83 LEVEL OF Ø,3ØØ AND Ø,Ø45,
   NEG,LEVEL AT -11ØEV;NEUTRON WIDTH=1,ØEV,
4) RESULTING SCATTER AND ABSORPTION SIGMAS AT Ø,Ø253EV ARE
   3,77 AND 38,558,
             ----UNRESOLVED RESONANCE PARAMETERS----
1) REDUCED NEUTRON WIDTH AND LEVEL SPACING FOR L=Ø FROM EVALU-
   ATION BY BLOCK ET AL,ORNL-3924,MAY 1966,P,31.SØ=1,8Ø4E-4,
2) REDUCED WIDTH FOR L=1-SAME REMARKS AS FOR W=182,MAT=1Ø6Ø,APPLY
3) RANGE IS 334EV TO 1ØØKEV,SCATTER LENGTH IS 7,2E-13,
4) LARGE LEVEL SPACING MAKES UNRESOLVED AVERAGE SIGMAS SUSPECT
   AT LOWER ENERGIES,HOWEVER NO CORRECTION HAS BEEN ATTEMPTED
   SINCE RESOLVED PARAMETERS TO 212ØEV (C17) ARE AVAILABLE AND
   WILL BE INCLUDED IN FIRST UPDATING.
----SMOOTH CROSS SECTIONS,ANGLE,AND ENERGY DISTRIBUTIONS----
1) SAME REMARKS AS FOR W-182,MAT=1Ø6Ø,APPLY EXCEPT AS NOTED BELOW
3) ENERGY,SPIN,AND PARITY OF GROUND STATE AND 6 EXCITED LEVELS
   TAKEN FROM NRC NUCLEAR DATA SHEETS,
6) N,2N THRESHOLD IS 7,31MEV,
   ----THE ABSORPTION INTEGRAL ABOVE Ø,5EV IS 487 BARNS,
   ----DECAY DATA FROM GOLDMAN,CHART OF THE NUCLIDES,8TH ED,----
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75-RE-185	1083	GE-NMPO	GEMP-587	JAN68	W.B.HENDERSON. J.W.ZWICK
75-RE-187	1084	GE-NMPO	GEMP-587	JAN68	W.B.HENDERSON. J.W.ZWICK

RHENIUM-185 (MAT 1083) and RHENIUM-187 (MAT 1084)

Background

This work* was undertaken specifically to supply ENDF/B with evaluated neutron cross sections of Re-185 and Re-187. It is an extension of an earlier evaluation* by A. Prince to include more recent data and make use of improved nuclear models. Most remarks below pertain to both isotopes. Where the information applies to only one isotope, it is so identified. Formal documention will be published as ENDF 115.

MF = 1, MT = 451 - GENERAL INFORMATION AND INTEGRAL DATA

The weight of the atom and neutron in the ratio, AWR, were taken from the Chart of the Nuclides.[1]

The absorption integral above 0.5 ev was computed from resolved and unresolved resonance parameters in File 2 and smooth absorption cross sections in File 3. For Re-185 the calculation gives 1748.3 barns versus 1726 ± 68[2], 1650 ± 90[3], 1753 ± 90[3], and 1828 ± 120[4] measured. For Re-187 the calculation gives 287.7 barns versus 292 ± 42[2], 308 ± 20[3], and 312 ± 22[4] measured. Using the abundances[5] of 0.3707 for Re-185 and 0.6293 for Re-187 the calculated value for natural rhenium is 829.1 barns versus 823 ± 52[2], 856 ± 65[3], 842 ± 50[3], 874 ± 58[4], and 694 ± 125[6] measured.

The calculated absorption cross section at 0.0253 ev for Re-185 is 114.0 barns versus 114 ± 3[2] measured and 105 ± 10[7] evaluated by Goldberg, et al. For Re-187** the calculation gives 74.8 barns versus 75 ± 4[2] and 73 ± 7[7]. For natural rhenium the calculation gives 89.3 varns versus 89 ± 5[2].

The calculated scattering cross section at 0.0253 ev for Re-185 is 20.6 barns and for Re-187, 10.1 barns. For natural rhenium this corresponds to 14.0 barns versus 14 ± 4[5] evaluated by Hughes and Schwartz.

The calculated total cross section at 0.0253 ev for Re-185 is 134.6 barns versus 118 ± 2[8] measured. The calculated value for Re-185 is a consequence of producing the 114.0 barns absorption from resonance parameters, which requires strong (or many) bound levels. The calculated scattering is the free atom cross section while the measured values contain solid state effects. The calculated total cross section for Re-187 is 84.8 barns versus 90 ± 2[8] measured. For natural rhenium the calculation gives 103.3 barns versus 100 ± 1[2] and 100 ± 2[8] measured.

The calculated reactivity worth of core-length natural rhenium samples in the fast-spectrum, refractory metal 710 Basic Critical Experiment No. 1[9] using the ENDF/B rhenium cross sections is -7.1×10^{-5}% per gram versus $(-5.7 \pm 1.0) \times 10^{-5}$

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*Work performed under U.S. Atomic Energy Commission Contract No. At(40-1)-2847.
**The capture cross section of Re-187 includes that leading to the 18.6 minute excited state.

measured. Although this evaluation produces natural rhenium absorption cross sections which are lower than most measured values above 100 ev, no change is recommended, pending further data testing, since absorption cross sections in agreement with those measurements lead to predictions of reactivity worth more negative than measured in both the 710 and the ZPR-9[10] fast critical experiments.

MF = 1, MT = 453 - RADIOACTIVE DECAY DATA

The data were taken from the Chart of Nuclides[1]. The decay constants were computed from the half lives of the ground states. Lacking a means of specifying branching ratios in the ENDF/B format, OS-186 was made the daughter of Re-186, since 95% of the decays[31] go that way.

MF = 2, MT = 151 - RESONANCE PARAMETERS

Resolved resonance parameters of Friesenhahn, et al[2] were used except for bound levels, which were determined from a multi-level Breit-Wigner fit to the low energy capture and total cross sections of Friesenhahn, et al[2]. The J values are from Goldberg, et al[7], where given; otherwise they were arbitrarily assigned 3 or 2 in the ratio 7 to 5 to facilitate multi-level calculations. In Re-185 a single bound level with J = 3 provided an adequate fit to the data. In Re-187 two bound levels were required and results were very insensitive to the J assignments. The spin-independent radii correspond to potential scattering cross sections of 7.45 and 7.55 barns in Re-185 and Re-187 respectively and were assigned to fit the measured low energy[2] total cross section of natural rhenium, as well as intermediate energy[2,11,12] values.

In the unresolved resonance region the average capture width and observed level spacing were taken from Friesenhahn, et al[2]. Strength functions for s, p, and d waves were assigned to be in approximate agreement with average optical model values and to fit the total cross section at intermediate energies. The resulting capture cross sections are somewhat lower than most measured[2,13-20] values, as mentioned in the description of MF = 1, MT = 451.

In the resolved resonance region the single-level Breit-Wigner formula is specified, and a "smooth" correction is supplied in File 3 to correct the resulting scattering and total cross sections to the values obtained by the multi-level evaluation. The capture cross sections in this region are also corrected by File 3 to correct for the contribution of unresolved resonances, which were included in the evaluation.

In the unresolved resonance region smooth File 3 cross sections correct for use of energy-independent level spacing and ignoring contributions of higher order than p-wave, both of which are presently limitations of ENDF/B. Since the threshold for inelastic scattering is above the upper boundary (10^5 ev) of the unresolved region, no difficulties are encountered by the ENDF/B exclusion of inelastic competition in the unresolved resonance formulation.

MF = 3, MT = 1 - SMOOTH TOTAL CROSS SECTION

The values in the resolved resonance region, E ≤ 99.8 ev in Re-185 and 93.8 ev in Re-187, correct the single-level Breit-Wigner results to multi-level values, and correct capture for the omission of unresolved resonance contributions.

The values in the unresolved resonance region, to 100 keV, correct for use of constant level spacing and omission of contributions of higher order than p-wave.

The values above 100 keV were obtained from ABACUS-NEARREX[21] calculations, where the optical model parameters, which are given in File 1, were adjusted to provide a good fit to the measured total cross section[11,12,22,23] of natural rhenium (and to the measured partial cross sections, but not at the expense of agreement with the total).

MF = 3, MT = 2 - SMOOTH ELASTIC CROSS SECTION

The values in the resolved resonance region correct the single-level results to multi-level values.

The values in the unresolved resonance region correct for use of constant level spacing and omission of d-wave contributions.

From 100 keV to 5 MeV the sum of shape and compound elastic cross sections from ABACUS-NEARREX was used. Above 5 MeV the compound elastic cross section was negligible and only the shape elastic cross section was used. The calculated values are somewhat higher than measured[24] at energies between 0.6 and 1.5 MeV and may indicate the need for an energy-dependent Moldauer Q value in the ABACUS-NEARREX calculation. The calculated values were nevertheless used since they provide an internally consistent set of partial isotopic cross sections.

MF = 3, MT = 4 - INELASTIC CROSS SECTION

From 100 keV to 1.5 MeV the cross sections for individual inelastic level excitations were computed in ABACUS-NEARREX. The energy, spin, and parity of 8 levels plus ground state of Re-185[24-26] and 11 levels plus ground state of Re-187[10,27] were used. From 100 keV to 1.0 MeV the $\sigma_{n,\gamma n'}$ cross section from ABACUS-NEARREX was also included. Above 1.0 MeV the $\sigma_{n,\gamma}$ and $\sigma_{n,\gamma n'}$ cross sections from ABACUS-NEARREX could not be used because lack of inelastic level data precludes correct competition. From 1 to 5 MeV the inelastic cross section was computed as the reaction cross section minus compound elastic and capture, the latter obtained as described in MF = 3, MT = 102 below. Above 5 MeV the inelastic cross section is $\sigma_{reaction}-\sigma_{capture}-(\sigma_{n,2n}+\sigma_{n,3n})$.

Comparison with Smith's measurements[24] shows underpredictions near threshold which again may indicate need for an energy-dependent Moldauer Q value.

MF = 3, MT = 16 - n,2n CROSS SECTION

The threshold and shape were taken from values supplied by Pearlstein[28]. The amplitudes were normalized to best fit measured values[7,29].

MF = 3, MT = 17 - n,3n CROSS SECTION

The threshold and shape were taken from values supplied by Pearlstein[28]. The normalization factor is the same as determined for the corresponding n,2n cross section.

MF = 3, MT = 27 - SMOOTH ABSORPTION CROSS SECTION

Same as MT = 102, smooth capture cross section. The n,p and n,α cross sections[7] over the energy range covered by this evaluation were considered negligible and were not included.

MF = 3, MT = 102 - SMOOTH CAPTURE CROSS SECTION

In the resolved resonance region the correction for the contribution of unresolved resonances is given.

In the unresolved resonance region the corrections for use of constant level spacing and omission of contributions of higher order than p-wave are given.

From 100 keV to 1MeV the values were obtained from ABACUS-NEARREX calculations. Above 1 MeV the shape of the ENDF/B Ta-181 (MAT 1035) capture cross section was used, normalized to the isotopic rhenium capture cross sections evaluated at 1 MeV.

MF = 3, MT = 251, 252, and 253 - ELASTIC $\bar{\mu}$, ξ, and γ

These were computed from the differential elastic cross sections calculated by ABACUS-NEARREX. A modified version of the CHAD[30] code was used.

MF = 4, MT = 2 - ELASTIC SECONDARY ANGULAR DISTRIBUTIONS

The transformation matrix and the Legendre coefficients for 19 moments were computed by CHAD as above. Comparison with Smiths measurements[24] shows good correlation of the odd moments and a tendency to overpredict the even moments which may stem from the deformed nature of the Re nuclei.

MF = 5, MT = 4, 16, 17 - SECONDARY ENERGY DISTRIBUTIONS

The fractional contributions of the discrete levels and $\sigma_{n,\gamma n'}$ to the total inelastic cross section were computed from threshold to 1.5 MeV using ABACUS-NEARREX results.

The (n,n'γ) secondary neutron energy distributions above 1.5 MeV and all (n,γn'), (n,2n) and (n,3n) secondary neutron distributions were described as Maxwellian with $T = \sqrt{E/25}$ MeV (same as Ta-181, MAT 1035). This spectrum is no doubt harder than the n,γn' secondaries and the secondaries following the first inelastic neutron emitted, but softer than the inelastic neutrons from direct reactions, which constitute the major portion of inelastic reactions above the onset of the n,2n reaction. An accurate calculation of these effects was beyond the scope of this evaluation.

MF = 7, MT = 4 - THERMAL NEUTRON SCATTERING LAW

The free gas law was specified below 1.0 ev. The free atom scattering cross section was specified as the value at 0.0253 ev, although in Re-185 the calculated value varies from 20.7 to 15.0 barns between 10^{-5} to 1.0 ev and in Re-187 it varies from 10.1 to 8.9 barns.

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8. V. P. Vertebny, et al., "Total Neutron Cross Sections of Re-185 and Re-187," Atomnaya Energiya 19, 250 (1965). [Transl. Soviet Atomic Energy 19, 1162].

9. F. L. Sims, et al., "Fast-Spectrum Refractory-Metal Critical Experiment Measurements," Trans. Am. Nucl. Soc. 9, 488 (1966).

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79-AU-197 1166 BNW.BNL PRI.COMM(67.72) JAN72 LEONARD.STEWART(STANDARD N.GAMMA)

GOLD-197

General Identification

MAT = 1037
ZA = 79197.0
AWR = 195.275 Ref 1
I = 1.5

Radioactive Decay

MT = 16	$Au^{196} \rightarrow Pt^{196}$	$\lambda = 1.30 \cdot 10^{-6}$ sec^{-1}	Ref 2
MT = 17	$Au^{195} \rightarrow Pt^{195}$	$\lambda = 4.18 \cdot 10^{-8}$ sec^{-1}	Ref 2
MT = 102	$Au^{198} \rightarrow Hg^{198}$	$\lambda = 2.974 \cdot 10^{-6}$ sec^{-1}	Ref 3
MT = 103	$Pt^{197} \rightarrow Au^{197}$	$\lambda = 9.625 \cdot 10^{-6}$ sec^{-1}	Ref 4
MT = 107	$Ir^{194} \rightarrow Pt^{194}$	$\lambda = 1.013 \cdot 10^{-5}$ sec^{-1}	Ref 4

General Discussion

The original intent was to supply data for ENDF/B in the thermal and resonance region. However, we have supplied σ_T and σ_γ for the entire energy range and (n,2n), (n,3n) and, (n,p) and (n,α) cross sections above threshold. Data on inelastic scattering, angular distributions, and secondary energy distributions are presently missing from the file.

Cross Sections

Low Energy

The low energy cross sections were calculated from the resolved resonance parameters given in file 2 up to 10^3 eV. Calculations made with the program UNICORN(5) gave a value of σ_γ (.0253 eV) = 95.28. The cross section was normalized to the accepted value of 98.8 barns(6) by adding a 1/v component of $\sigma_\gamma = 0.56\ (E)^{-\frac{1}{2}}$ barns. This component was also specified as a background to be added in file 3 to σ_T(MT=1) and σ_γ(MT=102) throughout the resolved resonance region.

The program UNICORN was then used to calculate 67 point values throughout the energy range 10^{-4} to 1.00 eV for σ_T(MT=1), σ_n(MT=2), and σ_γ(MT=102). These values are given in file 3. Lnσ vs E interpolation is specified since the energy mesh calculated by UNICORN is designed to give minimum interpolation error this way.

Resonance Region

The primary data sources considered were those of Julien(7) and Columbia University.(8) Both sets of data are very extensive and extend to 10^3 eV. Many more J values were determined by Julien while the Columbia University measurements apparently had a better sensitivity and furnished values of small Γ_n which were missing in some instances in Julien's results. Unfortunately there is a small discrepancy in energy scale in the two measurements (~6 eV at 900 eV). There are three instances where different J values were assigned to a resonance. The data of Julien were adopted for the ENDF/B. The Columbia University results have been used to supply missing values of Γ_n and, in one instance, a J value. The parameters of the 4.906 eV resonance are those of Wood, et al.(9) File 2 contains parameters for 63 resonances from 4.9 eV to 995.4 eV. For the resonances where J has not been determined the specification J = I = 1.5 was made to provide g = .5.

The UNICORN calculation of the resonance capture integral from 0.45 eV to 10^3 eV gave 1577.5 barns.

Unresolved resonance parameters are specified in the energy region 10^3 to 10^4 eV

Fast-Neutron Region

σ_T(MT=1)

The total cross section is specified in file 3. Values from 10^4 to 6×10^4 eV were obtained from a smooth curve guided by eye through the data of Newson.(10) The values from 6×10^4 to 2.5×10^6 eV were obtained in the same manner from the data given in BNL-325.(11) Data of Foster and Glasgow(12) were used to obtain the values for energies from 2.5 to 15 MeV.

$\sigma_{n,2n}$(MT=16), $\sigma_{n,3n}$(MT=17)

Point values of these cross sections were provided by Pearlstein(13) from model calculations. These data are contained in file 3.

σ_γ(MT=102)

The discrepancies in experimental data here are well known. Recent reviews and data which were considered were those of Bogart(14), Cox(15), Gibbons(16), and Grench(17). Although it is not clear to the authors that all of the significant discrepancies have been removed we have adopted the analysis of Bogart for this file. Point values are given in file 3 from 10^4 to 6×10^6 eV from Bogart and are extrapolated by the authors to 20 meV.

$\sigma_{n,p}$(MT=103) $\sigma_{n,\alpha}$(MT=107)

Point values are given in file 3 which were obtained by smooth curves drawn through the data contained on the graphs in Nuclear Data.(18)

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82-PB 1136 ORNL TO BE PUBL. JUL71 C.Y.FU AND F.PEREY

SUMMARY DOCUMENTATION FOR LEAD

C. Y. Fu and F. G. Perey
Oak Ridge National Laboratory

A complete evaluation is given of the neutron and photon production cross sections of natural lead from 0.00001 eV to 20 MeV. A detailed documentation[1] of the evaluation is now available. The following files and sections are included:

File 1. General Information

Section 451. Descriptive Data and Dictionary

File 2. Resonance Parameters

Section 151. General Designation for Resonance Information

Only effective scattering length[2] given.

File 3. Neutron Cross Sections

Section 1. Total Interaction

0.00001 eV to 1 eV - sum of the free atom scattering cross section and the 1/v capture cross section.

1 eV to 1 keV - BNL-325.[3]

1 keV to 0.47 MeV - resonance structure based on reference 4 and values adjusted to conform with other data.[5]

0.47 MeV to 20 MeV - reference 6.

Section 2. Elastic Scattering

Derived by subtracting the nonelastic from the total.

Section 3. Nonelastic Interaction

Below the (n,2n) threshold, it was determined by summing the partial cross sections. Above the (n,2n) threshold, it was obtained from optical model calculations. The results are in good agreement with nonelastic data.

Section 4. Total Inelastic Scattering

Below the (n,2n) threshold, it was calculated for each isotope using the Hauser-Feshbach theory. Above the (n,2n) threshold, it was obtained from the ratio of σ(n,n') and the sum of σ(n,2n) and σ(n,3n). The ratio was calculated by a method similar to the Pearlstein formalism,[7] but direct-interaction contribution to σ(n,n') was considered. Data were available below 8 MeV and near 14 MeV and were in good agreement with the calculation.

Section 16. (n,2n) Reaction

Below approximately 14 MeV, it was determined by subtracting σ(n,n') from the nonelastic. Above 14 MeV it was obtained by subtracitng σ(n,3n) from the nonelastic. Data were available near 14 MeV.

Section 17. (n,3n) Reaction

Calculated using the Pearlstein formalism.[7] No data were available.

Section 51 thorugh 85. Inelastic Scattering Exciting Levels

Below 4.4 MeV of excitation energy 48 levels in ^{206}Pb, 49 levels in ^{207}Pb and 22 levels in ^{208}Pb were considered. Calculations of the Hauser-Feshbach type were performed to supplement experimental data which were available for the lowest-lying levels. DWBA calculations were made to account for direct-interaction contributions to 20 of these levels. The results were merged to form 35 levels in natural lead.

Section 91. Inelastic Scattering Exciting Continuum

Derived by subtracting the level contributions from the total inelastic.

Section 102. Radiative Capture

Up to 10 eV a 1/v dependence was assumed using 0.178 barns at 0.0253 eV.[2] A smooth curve was drawn through experimental data for higher energies.

Section 251 through 253. $\bar{\mu}_L$, ξ , γ

Derived from elastic angular distributions and kinematics.

File 4. Angular Distribution of Secondary Neutrons

All distributions were given in the Legendre polynomial representations and in the center of mass system.

Section 2. Elastic Scattering

0.00001 eV to 5 MeV - Legendre coefficients obtained by fitting data.

5 MeV to 20 MeV - optical-model calcualtion.

Optical-model parameters were derived from jointly fitting elastic angular distributions at 7 and 14 MeV, and inelastic level excitations. The same set of parameters were used in all relevant calculations.

Section 51 thorugh 85. Inelastic Scattering Excited Levels

Calculated and represented in the same way as in file 3 and compared favorably with data.

Section 91. Inelastic Scattering Excited Continuum

Assumed isotope.

File 5. Energy Distribution of Secondary Neutron

Section 16. (n,2n) Reaction

Maxwellian distribution with temperatures derived from level density and Le Couteur theory for neutron cascade.[8]

Section 17. (n,3n) Reaction

See Section 16.

Section 91. Inelastic Scattering Excited Continuum

Evaporation distribution with temperatures derived from level density, compared favorably with sparse data.

File 12. Multiplicities of Gamma Rays Produced by Neutron Reactions

Section 3. Nonelastic Interaction

Derived from file 15, section 3.

File 14. Angular Distribution of Secondary Gamma-Rays

Section 3. Nonelastic Reaction

Assumed isotropic.

File 15. Energy Distribution of Secondary Gamma-Rays

Section 3. Nonelastic Interaction

0.00001 eV to 10 eV - thermal-neutron capture spectrum.

1 keV to 573 keV - averaged spectrum derived from resonance capture yields for a small number of resonances.

10 eV to 1 keV - linear interpolation between above two spectra.

573 keV to 20 MeV - calculated spectra resulting from inelastic scattering, (n,2n) and (n,3n) reactions, given for neutron energy intervals ranging from 0.25 MeV to 1 MeV, compared favorably with data. See reference 1 for method of calculation.

File 23. Photon Interaction Cross Sections

Taken from the evaluation by W. H. McMaster et al.[9]

It included sections 501, 502, 504, 516 and 602.

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90-TH-232 1117 B+W BAW-317 (1970) NOV66 WITTKOPF.ROY.LIVOLSI (REV.APR70)

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                    ENDF/B MATERIAL NO= 1117
TH-232     B AND W     EVAL=NOV66 WITTCOPF, ROY, AND LOVOLSI
BAW=317 (1970)         DIST=MAY67 REV-APR70
*          *           *          *          *          *
 THORIUM-232       (B AND W)    WITTCOPF, ROY, AND LIVOLSI
        *          *          *          *          *
        DATA COMPILED NOV., 1966 AND MODIFIED MAY, 1969
        EVALUATION DESCRIBED IN BABCOCK AND WILCOX REPORT,
        BAW-317
        *          *          *          *          *
ENERGY RANGE (0.00001 TO 10 EV.
   TOTAL X/S ACCORDING TO MEMO FROM B.R. LEONARD TO CSEWG ON AUG.
   8, 1969.  A VALUE OF 10.15 B FOR THE POTENTIAL X/S WAS PROVID
   ED AS THE BEST FIT TO THE EXPERIMENTALLY MEASURED DATA.
   THE 2200 M/SEC CAPTURE CROSS SECTION WAS  7.40 B, OF WHICH
   6.96 B IS DUE TO A NEG. ENERGY LEVEL, 0.245 IS DUE TO THE
   POSITIVE ENERGY LEVELS, AND 0.195 IS 1/V CONTRIBUTIONS.
   ELASTIC SCATTERING X/S DERIVED AS THE DIFFERENCE BETWEEN
   THE TOTAL AND THE CAPTURE X/S.
ENERGY RANGE (0.01 TO 50.0 KEV)
   BNL-325, 2ND ED. PROVEDED THE RECOMMENDED VALUES FOR ALL
   RESOLVED RESONANCES UP TO 3.006 KEV. THE LAST GROUP OF
   RESONANCES UP TO 3.931 KEV WERE OBTAINED FROM THE MEASUREMENT
   MADE BY GRAG, ET AL., PHYS. REV.134,895(1964). ALL RESOLVED
   RESONANCES WERE TAKEN AS S-WAVE.
   THE RANGE FROM 3.931 TO 50 KEV IS COVERED BY THE UNRESOLVED
   RESONANCE REGION AND THE PARAMETERS ARE DESRIBED IN BAW-317.
   A BACKGROUND CROSS SECTION IS GIVEN IN FILE 3 FOR THE
   CAPTURE X/S TO ACCOUNT FOR MISSED P-WAVE RESONANCES  IN THE
   RESOLVED RESONANCE REGION.
ENERGY RANGE (0.05 TO 15 MEV)
   THE TOTAL X/S WAS TAKEN FROM THE DATA GIVEN IN BNL-325,
   2ND ED. THE ELASTIC X/S WAS OBTAINED AS THE DIFFERENCE
   BETWEEN THE TOTAL AND ALL NON-ELASTIC CROSS SECTIONS.
   THE RADIATIVE CAPTURE X/S WAS TAKEN FROM THE DATA GIVEN IN
   BNL-325, 2ND ED.  THE FISSION X/S WAS TAKEN FROM AN EVALUATION
   MADE BY DAVEY, N.S.E., 26,149(1966) UP TO 10 MEV AND FROM
   BNL-325, 2ND ED. UP TO 15 MEV.
   THE NUMBER OF NEUTRONS PER FISSION IS IN AGREEMENT WITH H.
   CONDE AND M. HOLMBERG, IAEA CONF.(1965) VOL.2. P61.
   FOR SECONDARY ENERGY DISTRIBUTION  OF FISSION NEUTRONS, THE
   TEMPERATURE IS IN AGREEMENT WITH THE WORK BY E.BARNARD ET AL.
   NUC. PHYS. 71,228(1965).
   INELASTIC           THRESHOLD SET AT 50 KEV AS FROM A.B.SMITH
   PHYS.REV. 126,718(1962). ALL OTHER DISCRETE LEVELS WERE
   OBTAINED FROM WORK OF N.P.GLASKOV, AT. ENERGY, 14,400(1963),
   R. BATCHELOR ET AL. NUC. PHYS. 65,236(1965), AND S.O. MOORE,
   BNL-818 (1963).
   THE (N,2N) X/S WAS OBTAINED AS AN UNWEIGHTED AVERAGE THROUGH
   SEVERAL EXPERIMENTAL DATA SETS PUBLISHED BETWEEN 1964 AND 1956
   THE (N,3N) X/S WAS OBTINED FROM THE WORK OF M.H.TAGGART AND
   H. GOODFELLOW, JNE 17,437(1963).
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91-PA-233 1119 BAPL PRI.COMM.(1970) JAN70 P.C.YOUNG,D.R.HARRIS

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                      ENDF/B MATERIAL NO= 1119
 PA-233    BAPL          EVAL=JAN70 P.C.YOUNG,BAPL,W,MIFFLIN,PA.15122
                         DIST=OCT70 REV-OCT70   1,00000- 3 1,50000+ 7
     *          *          *          *          *          *
 DATA MODIFIED OCTOBER 70 TO CONFORM TO ENDF/B-VERSION II FORMATS
     *          *          *          *          *          *
MF=1,MT=451  COMMENTS AND DICTIONARY
MF=1,MT=452  NU(E)=C1+C2*E, WHERE C1 AND C2 WERE OBTAINED FROM A
   DERIVED EMPIRICAL RELATION DEPENDENT ON Z AND A
MF=1,MT=453  DECAY DATA   91PA233-BETA-92U233-ALPHA-90TH229
MF=2,MT=151  RESON PARAMETERS FROM * REF.1(28 RESON,UP TO 17.5EV),
   REF.2(12 RESON,17.5-37.5EV), RESOLVED RESON ENERGY RANGE= 0,001
   TO 36.5 EV. AVE RESON PARAMETERS DEDUCED FROM THE 27 POSITIVE
   RESON GIVEN IN REF.1, UNRESOLVED RESON ENERGY RANGE= 38.5 EV TO
   10 KEV. THE 12 GN0 FROM REF.2 ADJUSTED TO YIELD SAME RESON INT
   CONTRIB INPLIED BY THE AVE RESON PARAMETERS, THE RESULTING GN0
   FOR THE 40 RESOLVED RESON AND THE AVE GN0 FOR THE UNRESOLVED
   RESON ADJUSTED TO YIELD A CAPT RESON INT(0.5EV-10MEV)=859.96BN(
   INCLUDING THE CONTRIB OF THE MF=3,MT=102 DATA), THE GN0 FOR THE
   NEG RESON THEN ADJUSTED TO YIELD A 0.0253EV CAPT XSECT= 39.79BN
 FILE 3 CONTAINS SMOOTH DATA IN THE ENERGY RANGE 10 KEV TO 15 MEV
MF=3,MT=1    TOTAL CROSS SECTION - REQUIRED TO BE CONSISTENT IN
   BOTH MAGNITUDE AND ENERGY VARIATION WITH THE TOTAL X-SECTION
   OF NEIGHBORING NUCLIDES, E.G. TH232,U233,U235,U238, AND PU239.
MF=3,MT=2    ELASTIC SCATTERING CROSS SECTION = TOTAL X-SECTION
   MINUS NONELASTIC X-SECTION, IN ADDITION, REQUIRED TO BE CONSIS-
   TENT IN ENERGY VARIATION WITH ELASTIC SCATTERING X-SECTION OF
   NEIGHBORING NUCLIDES (TH232,U235,U238) AND TO JOIN SMOOTHLY AT
   10 KEV WITH A VALUE NEARLY EQUAL TO THE POTENTIAL SCATTERING
   X-SECTION (=9.995 BARNS, REF.2).
MF=3,MT=3    NONELASTIC CROSS SECTION = SUM OF THE (N,F),
   (N,NPRIME),(N,2N),(N,3N) AND (N,GAMMA) CROSS SECTIONS.
MF=3,MT=4    INELASTIC SCAT XSECT  - TAKEN FROM REF.3 , Q-VALUE =
   = 18.7 KEV ( ENERGY OF THE FIRST EXCITED STATE IN 91PA233 )
MF=3,MT=16 AND 17   (N,2N) AND (N,3N) XSECT - TAKEN FROM REF.3
   Q-VALUE CALCULATED USING ATOMIC MASSES FROM REF.4.
MF=3,MT=18   FISSION CROSS SECTION - COMPOSITE CURVE AS FOLLOWS -
   0.48=1.00MEV 233PA(N;F)= 238U(N,F) FROM REF.5.
   1,00=1.50MEV LOG(233PA(N;F)) LINEAR IN LOG(E)
   1.50-5.00MEV 233PA(N;F)= (C1/C2)*238U(N,F) FROM REF.5.
   C1=0.832 = CALC. PLATEAU VALUE OF 233PA(N,F) REF.6.
   C2=0.511 = AVG. VALUE OF 238U(N,F) (REF.5),2.6-5.6 MEV
   5.00-9.00MEV 233PA(N,F) HAS ENERGY VARIATION SIMILAR TO THAT
   FOR (N.F) OF U234,U236 AND NP237 FROM REF.5.
   9.00-12.5MEV 233PA(N,F)=(C1/C2)*238U(N,F) FROM REF.7.
   C1=1.56 = DERIVED VALUE OF 233PA(N,F) FOR THE SECOND PLATEAU
             NEAR 9.0 MEV.
   C2=1.02 = 238U(N,F)(REF.7) AT THE SECOND PLATEAU.
   12.5-15.0MEV 233PA(N;F) HAS SAME ENERGY VARIATION AS THAT FOR
   236U(N,F)(REF.7)
   Q-VALUE = CALCULATED ENERGY RELEASE PER FISSION
MF=3,MT=51,52,53,54,55,91  PARTIAL INELASTIC SCAT XSECT=FROM REF.3
MF=3,MT=102  CAPTURE CROSS SECTION - COMPOSITE CURVE AS FOLLOWS -
   0.01-0.08MEV 233PA(N;GAMMA) SELECTED TO JOIN SMOOTHLY WITH THE
   (N,GAMMA) CALCULATED FROM AVERAGE RESONANCE PARAMETERS
   0.08-15.0MEV 233PA(N;GAMMA) = 2*238U(N,GAMMA) FROM REF.8.
   NORMALIZATION FACTOR(=2) CHOSEN SO THAT 233PA(N,GAMMA) =
   236U(N,GAMMA)(REF.8) AT 0.9 MEV
```

MF=3,MT=251 MU=BAR (AVG,COSINE OF THE SCATTERING ANGLE IN THE LAB SYSTEM FOR ELASTIC SCATTERING), CALCULATED FROM THE U(1,M) AND LEGENDRE COEFFICIENTS GIVEN IN FILE 4

MF=3,MT=252 XI (AVG,LOGARITHMIC ENERGY DECREMENT),

MF=3,MT=253 GAMMA (SLOWING DOWN PARAMETER),
THE ENERGY DEPENDENCE OF THE TWO ABOVE QUANTITIES IS DETERMINED BY THE LEGENDRE COEFFICIENTS GIVEN IN FILE 4. COMPLETELY GENERAL EXPRESSIONS IN POWERS OF AWR**-1 HAVE BEEN DERIVED FOR THE CONSTANTS WHICH DETERMINE THE CONTRIBUTION OF EACH OF THE LEGENDRE COEFFICIENTS,

MF=4,MT=2 TRANSFER MATRIX U (FROM C.M. TO LAB), A GENERAL EX= PRESSION FOR U(L,M) IN POWERS OF AWR**-1 HAS BEEN DERIVED. THE LEGENDRE COEFFICIENTS WERE TAKEN DIRECTLY FROM REF.3, AND ARE BASED ON THE DATA FOR TH232,

MF=4,MT=51,52,53,54,55 ANG DIST OF NEUTRONS SCAT INELASTICALLY FROM 5 DISCRETE LEVELS ASSUMED ISOTROPIC IN THE CM SYSTEM

MF=5,MT=16,17,91 ENERGY DEPENDENCE OF SECONDARY NEUTRONS DEFINED BY AN EVAPORATION SPECTRUM , ENERGY DEPENDENCE OF THETA CALCU- LATED USING THE FORMULATION IN REF.9

MF=5,MT=18 SIMPLE FISSION SPECTRUM - THETA (CONSTANT) CALCULATED USING THE FORMULATION GIVEN IN REF.10.

MF=7,MT=4 THERMAL SCATTERING LAW - FREE ATOM X-SECTION=10BARNS.

REFERENCES

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10,TERRELL, PHYS AND CHEM OF FISS, VOL II, 3 (1965)

92-U-233 1110 BAPL WAPD-TM-691(1969) MAR71 N.M.STEEN (DATA MOD.MARCH 71)

ENDF/B MATERIAL NO= 1110
U-233 EVALUATED DATA -7/69-REV 3/71 - N.M.STEEN BAPL

```
*****************************************************************
*            1/E WEIGHTED INTEGRALS ABOVE 0.5EV                 *
*            CALC. INTEGRAL        EXPERIMENTAL VALUE*          *
*  FISSION   761. +/- 10. BNS        771. +/- 25. BNS           *
*  CAPTURE   134. +/- 15. BNS        135. +/- 6. BNS            *
*  ALPHA     0.176 +/- 0.02          0.175 +/- 0.006            *
*          *EXPERIMENTAL RESULTS ARE WEIGHTED AVERAGES          *
*****************************************************************
*            0.0253EV THERMAL PARAMETERS                        *
*                  ETA       2.29720                            *
*                ALPHA       0.0874                             *
*             NU-TOTAL       2.49798                            *
*              SIGMA-F       525.11                             *
*              SIGMA-C       45.90                              *
*              SIGMA-A       571.01                             *
*              SIGMA-T       585.4                              *
*              SIGMA-S       14.39                              *
*****************************************************************
*              THERMAL G FACTORS                                *
*    T(C)    G(ETA)    G(ABS)    G(FISS)    G(CAPT)             *
*     20     0.9976    0.9990    0.9966     1.0263              *
*     30     0.9973    0.9991    0.9964     1.0293              *
*     40     0.9971    0.9992    0.9963     1.0324              *
*     50     0.9968    0.9993    0.9961     1.0356              *
*     75     0.9961    0.9993    0.9954     1.0436              *
*    100     0.9956    0.9997    0.9953     1.0502              *
*****************************************************************
*          FISSION SPECTRUM - INTEGRAL PROPERTIES               *
*              MEAN ENERGY  - 2.012 MEV                         *
*                 VARIANCE  - 2.613 MEV**2                      *
*             AGE IN WATER  - 26.44 CM**2                       *
*****************************************************************
```

FISSION CROSS SECTIONS ARE BASED ON THE FOLLOWING DATA
1) 0.4EV - 1.5KEV ****** DATA OF WESTON ET.AL. ORNL-TM-2140 (ADLER FIT TO 60EV),1968
2) 1.5KEV - 15.MEV ***** HART(U.K.) DATA AHSB(S) R124, 1967
3) THERMAL - REVISED ORNL-RPI EXPERIMENT (PRIV. COM. FROM L. WESTON,1968).

CAPTURE CROSS SECTIONS ARE BASED ON THE FOLLOWING DATA
1) 0.4EV - 1.5KEV ********* DATA OF WESTON ET. AL. ORNL-TM-2140 (ADLER FIT TO 60EV)
2) 1.5KEV - 1.0MEV ******* FIT TO ALPHA(E) DATA OF DIVEN AND THE ABOVE FISSION DATA
3) 1.0MEV - 15.MEV ******* A SIMPLE ANALYTIC EXPRESSION OF THE FORM A/(1 + B*SQRTE)*SQRTE
4) THERMAL - REVISED ORNL-RPI EXPERIMENT(PRIV. COM. AND FISSION CROSS SECTIONS IN THIS FILE.

SCATTERING CROSS SECTIONS ABOVE 1.50EV WERE TAKEN DIRECTLY FROM THE EVALUATION BY DRAKE ET AL(GA-7076,1967) BELOW 1.50EV THE VALUES ARE CONSISTENT WITH A 2200 M/S VALUE OF 14.39BN.

NU-BAR DATA (PROMPT + DELAYED) IS BASED ON THE DELAYED VALUE OF 0.007 FROM THE WORK OF KEEPIN. THE PROMPT NU-BAR DATA ARE BASED ON WEIGHTED LEAST SQUARES FITS TO THE AVAILABLE DATA. IN THE RANGE 0.0 - 1.3 MEV THE FIT IS LINEAR. FROM 1.3MEV - 15.MEV A SECOND ORDER FIT WAS USED.

SLOW NEUTRON EQUILIBRIUM FISSION SPECTRUM IS BASED ON
THE FOLLOWING DATA
1) THE SHAPE FUNCTION, N(E), CONSISTS OF FOUR
COMPONENTS, THESE REPRESENT THE FOLLOWING
A) DELAYED DISTRIBUTION- TAKEN TO BE
A MAXWELLIAN WITH MEAN ENERGY = 0,450MEV,
B) AN EMISSION SOURCE THAT IS STATIONARY
IN THE LAB COORDINATE SYSTEM, THIS
COMPONENT ACCOUNTS FOR 10 PERCENT OF THE
NEUTRONS , THE FORM OF THE EMISSION FROM
THIS SOURCE IS EVAPORATION WITH EBAR=3,05MEV,
C) TWO MOVING EMISSION SOURCE COMPONENTS
REPRESENTING THE LIGHT AND HEAVY FRAGMENTS,
THE EMISSION FROM THESE COMPONENTS IS
ASSUMED TO BE ISOTROPIC IN THE CENTER OF
MASS CORRDINATE SYSTEM AND REPRESENTED BY
A SINGLE EVAPORATION SPECTRUM FOR EACH
FRAGMENT, THE LIGHT TO HEAVY FRAGMENT
FRAGMENT YIELD RATIO IS TAKEN TO BE 1,382,
D) THE FUNCTIONAL FORM FOR THE PROMPT
SPECTRUM, NP(E), IS GIVEN BY THE EQUATION
NP(E) = 0,1*NS(E,TS) + 0,9*(B*NH(E,EH,TH)
+ (1-B)*NL(E,EL,TL)),
WHERE TS=1,52603MEV,EL=1,021MEV,TL=0,680MEV,
EH=0,475MEV,TH=0,381159MEV,B=0,4198
2) MEAN ENERGY FOR THE EQUILIBRIUM SPECTRUM WAS
DETERMINED BY CONSIDERATION OF BIAS IN GROUP
EXPTL ASSEMBLIES WITH VARYING LEAKAGES, DE-
DISCUSSED IN WAPD-TM-691(1969), MORE DETAILS
AVAILABLE IN WAPD-TM-997(4/71)
THE GENERAL EVAPORATION DISTRIBUTION,LF=4,
HAS BEEN USED TO REPRESENT THE COMPONENT
0,9* (B*NH(E,EH,TH) + (1-B)*NL(E,EL,TL))
THE REMAINING DATA IN THIS MATERIAL WERE TAKEN DIRECTLY
FROM THE PREVIOUS ENDF/B (MAT, NO, 1041) DATA
FOR U-233 PROVIDED BY M. DRAKE OF GULF GEN,
ATOMICS (GA-7076,1967),

ENDF/B MATERIAL NO= 1042

U-233RSFP B+W   EVAL=DEC66 W.A.WITTKOPF(FOR THERM.REACTORS)
BAW-320 (DEC.1966)   DIST=JUL68 REV-JUN70

* * * * * * *

DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS

* * * * * * *

THIS DATA SET IS FOR USE IN BURN-UP CALC. FOR THERMAL REACTORS

* * * * * * *

U-233 LUMPED FISSION PRODUCT NO.1(LFP1); RAPIDLY SATURATING;
GENERATED DECEMBER 1966; REFERENCES ARE

1. W A WITTKOPF, BAW-320, (DEC, 1966), GIVES DETAILS AND METHODS
2. J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962), OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3. N F WIKNER AND S JAYE, GA-2113 (JUNE 1961), GIVES NUCLEAR DATA

THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS

1. THE XE-135 CHAIN
2. THE SM-149 CHAIN
3. LFP1 (CD-113, SM-151, GD-155, GD-157)
4. LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143, ND-145, PM-147, SM-152, EU-153)
5. LFP3 (ALL OTHER FISSION PRODUCTS).

CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO BE INFINITELY DILUTE. THUS; DATA IS SUPPLIED ONLY FOR MF=1, MT=451 AND MF=3, MT=27

92-233-4
SSFP

ENDF/B MATERIAL NO= 1066

U-233SSFP B+W EVAL=DEC66 W.A.WITTKOPF (FOR THERM,REACTORS)
RAW-320 (DEC.1966) DIST=JUL68 REV-JUN70

* * * * * * *

DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS

* * * * * * *

THIS DATA SET FOR THERMAL REACTORS ONLY

* * * * * * *

U-233 LUMPED FISSION PRODUCT NO.2(LFP2), SLOWLY SATURATING,
GENERATED DECEMBER 1966, REFERENCES ARE
1, W A WITTKOPF, BAW=320, (DEC, 1966), GIVES DETAILS AND METHODS
2, J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3, N F WIKNER AND S JAYE, GA=2113 (JUNE 1961), GIVES NUCLEAR DATA

THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS

1, THE XE=135 CHAIN
2, THE SM=149 CHAIN
3, LFP1 (CD-113, SM=151, GD-155, GD-157)
4, LFP2 (MO-95, TC-99, RH-103, XE=131, CS-133, ND-143,
ND-145, PM-147, SM-152, EU-153)
5, LFP3 (ALL OTHER FISSION PRODUCTS),

CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO BE INFINITELY DILUTE. THUS, DATA IS SUPPLIED ONLY FOR MF=1, MT=451 AND MF=3, MT=27

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                          ENDF/B MATERIAL NO= 1067
 U-233NSFP     B+W      EVAL=DEC66 W,A,WITTKOPF (FOR THERM,REACTORS)
 BAW-320 (DEC,1966)     DIST=JUL68 REV-JUN70
 *          *          *          *          *          *          *
 DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
 *          *          *          *          *          *          *
 THIS DATA SET FOR THERMAL REACTORS ONLY
 *          *          *          *          *          *          *
U-233 LUMPED FISSION PRODUCT NO,3(LFP3), NON-SATURATING,
GENERATED DECEMBER 1966, REFERENCES ARE
1, W A WITTKOPF, BAW-320, (DEC, 1966), GIVES DETAILS AND METHODS
2, J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
  OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3, N F WIKNER AND S JAYE, GA-2113 (JUNE 1961), GIVES NUCLEAR DATA

  THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL
FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED
BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS
     1, THE XE-135 CHAIN
     2, THE SM-149 CHAIN
     3, LFP1 (CD-113, SM-151, GD-155, GD-157)
     4, LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143,
              ND-145, PM-147, SM-152, EU-153)
     5, LFP3 (ALL OTHER FISSION PRODUCTS),

  CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED
IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO
BE INFINITELY DILUTE,  THUS, DATA IS SUPPLIED ONLY FOR MF=1,
MT=451 AND MF=3, MT=27
```

ENDF/B MATERIAL NO= 1255

FISSION FRAGMENT RESIDUAL LUMP FOR U-233
PUT IN ENDF/B2 FORMAT BY ZIZO LIVOLSI, BABCOCK-WILCOX, AUG 1971
THIS IS A FICTITIOUS NUCLIDE THAT INCLUDES INTO A SINGLE LUMP ALL THE FISSION FRAGMENTS FROM U-233 WITH EXCEPTION OF THE 53 NUCLIDES EXPLICITELY DESCRIBED IN ENDF/B, WALKER(1) HAS CALCULATED THE SUM OF THE YIELD X SIGMA AND YIELD X RI, BY NORMALIZING THE SUM OF YIELDS TO 2

AT 2200M	SIGMA-C =	1,265	BARNS
ENDF DATA TOTAL CAPTURE INTEGRAL	=	5,63	BARNS

REFERENCES

1. WH WALKER, PRIV. COM. TO WA WITTKOPF (6/30/71)
2. FE LANE, AECL-3038(11/1969)

92-U-234 1043 GGA GA-8135(1967) JAN67 M.K.DRAKE.P.NICHOS

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                    ENDF/B MATERIAL NO= 1043
U-234      GGA         EVAL=JAN67 DRAKE AND NICHOLS
GA-8135 (SET,1967)   DIST=JUL68 REV-APR70
URANIUM-234 NEUTRON CROSS SECTIONS
DATA TAKEN FROM REPORT BY DRAKE AND NICHOLS  (GA-8135)

DATA MODIFIED FOR ENDF/B-II FORMATS (APRIL, 1970)
PARAMETERS FOR NEGATIVE LEVEL CHANGED (APRIL, 1970)

MF=3 MT=1   TOTAL         OBTAINED BY ADDING PARTIAL CROSS SECTIONS
MF=3 MT=2   ELASTIC       SAME AS U-238 (GA-6087)
MF=3 MT=3   NONELASTIC    SUM OF (N-2N),(N-3N),(N-G),(N-F),(INEL)
MF=3 MT=4   INELASTIC     FROM PARKER (AWRE 0-37/64)
MF=3 MT=16 (N-2N)         FROM PARKER (AWRE 0-37/64)
MF=3 MT=17 (N-3N)         FROM PARKER (AWRE 0-37/64)
MF=3 MT=18 FISSION        (GA-8135)
Q-VALUE REF,A,PRINCE,PRIVATE COMMUNICATION 16APR68
MF=3 MT=102 (N-GAMMA)   (GA-8135)   ALSO  MT=27 ABSORPTION
MF=3 MT=251,252,253 CALCULATED BY CHAD
MF=4 MT=2   DIFF ELASTIC(GA-8135)    SAME AS THORIUM (GA-6404)
MF=5 MT=16                (GA-8135)
MF=5 MT=17                (GA-8135)
MF=5 MT=18                (GA-8135)
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92-U-235 1157 AI.BNW.ANC BNWL-1586.ANCR-1044 AUG71 ALTER.DUNFORD.LEONARD.PITTERLE

ENDF/B-III SUMMARY DOCUMENTATION FOR U^{235}

Contributors:

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H. Alter: Atomics International[(2)]
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January 1972

(1) ANCR 1044
(2) AI-AEC-12916; AI-AEC-13013
(3) BNWL-1586
(4) WARD-4210T4-1

Thermal Data

The cross section shapes in this evaluation were derived, in general, by perturbing the results of an existing evaluation in order to reproduce the desired g values. The results of existing precision experimental differential measurements were used as a guide to the nature of the perturbations.

An objective of the evaluation was to provide cross-section shapes which were smooth in the thermal region and would not produce irregularities in the behavior of thermally averaged quantities as a function, say, of neutron temperature.

Point representation of the data intended to be in the ENDF/B-I files were received from C. R. Lubitz. These files covered the energy range 10^{-3} to 5 eV. It was determined that these files contained apparently unintended irregularities as large as one percent in the entries below 4 meV. These entries were smoothed and the data files extended to 10^{-4} eV. Calculation of "g" factors showed that the value of g_f was about 0.2 percent greater than the desired value. The original evaluation of the low-energy fission cross section was reported to have been made by fitting σ_f data of LRL and Hanford. Accordingly, a new fit was made including these data and also the fission data of Safford and Melkonian. A smooth fit was obtained, the main difference from the original fit being the reduction of the rise in cross section at energies below about 0.02 eV. The fission cross section was fitted simultaneously with the capture cross section using an alpha variation deduced by Westcott. In order to achieve a smooth fit to the fission data the file was modified slightly for energies up to 0.18 eV. The capture cross section file was modified for energies up to 0.1 eV.

The cross-section shapes derived for sub-thermal neutron energies are based in large part on precision total cross section measurements of Safford, et al. and the $1 + \alpha$ measurement of Safford and Melkonian. The total cross section data of Safford, et al. obtained with liquid samples is shown below compared with the ENDF/B values.

	$\sigma_T \sqrt{E}$	
Neutron Energy	Safford, et al.	ENDF/B
0.000818 eV	115.71 ± 0.35	115.56
0.00128 eV	115.79 ± 0.29	115.49

The ENDF/B scattering cross sections at these energies is 16 b and a ±3 b uncertainty in this cross section contributes about ±0.1 b - $eV^{1/2}$ to calculated $\sigma_T\sqrt{E}$ values.

A summary of the 2200 m/s cross section parameters is given below.

σ_T	694.276
σ_S	15.776
σ_f	580.2
σ_c	98.3
ν	2.423 (Delayed + Prompt)
α	0.1694
η	2.07196

Resolved Resonance Region

The resolved resonance region for ^{235}U in ENDF/B-III extends from 1 to 82 eV. The description uses single level parameters plus a smooth file. Parameters were derived from a simultaneous fit to the following sets of data:

1) Simultaneous capture and fission measurements by deSaussure, et al. The strength of this experiment is that it measured the two most important partial cross sections of U^{235} simultaneously, under the same conditions of resolution and background. Moreover, care was taken to correct for such effects as backgrounds, resonance self-shielding, and scattering in the fission chamber. These data were used principally to indicate the ratio of capture to fission for the resonances.

2) Total cross section measurements of Michaudon. These data were obtained at liquid nitrogen temperatures and fairly high resolution. They turned out to give in most cases the best indication of the total widths of the resonances. The data were available only as cross section vs. energy, with results from several samples mixed together. Total cross sections are measured from transmission of samples, and the analysis should really be performed on the transmission data for each sample.

3) Fission cross sections measured by Blons, et al. on the Saclay linear accelerator. These data were obtained at liquid nitrogen temperature, with resolution similar to that of Michaudon's total cross section measurement. The Blons data are the best resolution fission data, but below about 35 eV the normalization gets progressively more erratic because of difficulty in interpreting the backgrounds in the presence of a B-10 filter used to eliminate low energy overlap neutrons.

4) Fission cross sections measured by Cao, et al. on the linear accelerator at C.B.N.M. (Geel). These data are the highest resolution room temperature measurements of σ_f for U^{235}. They are useful for comparing with the Blons data to confirm the effectiveness of the Doppler corrections in the analysis code. They go to a lower energy than the Blons data, 6 eV vs. 17 eV. However, the Cao data are troubled by erratic background corrections in the vicinity of resonances in filters used to determine backgrounds.

Cross Section Normalization

Since this analysis covered only the resonance region above 1.0 eV, it was necessary to normalize all data to the existing ENDF/B-II low energy file. Of the principal data sets, only the deSaussure measurements extends to this low energy. His fission data were raised by 1.5% to bring their integral from 0.45 eV to 1.0 eV into better agreement with that from the ENDF/B low energy file. The difference in the capture integrals was 2.4%. Nevertheless, the capture was raised only 1.5% in order that deSaussure's α ratios might be preserved.

The Cao data were raised 7% to bring them into agreement with the renormalized deSaussure data. The Blons data, which already agreed well with the renormalized deSaussure data above 40 eV, were given an energy-dependent renormalization. The ratios to deSaussure values of a series of incremental resonance integrals were fit with a fourth degree polynomial. This polynomial was then used to normalize the Blons data. The resulting correction ranged from about 19% at 18 eV to zero at 40 eV.

Single level parameters were derived by fitting the experimental data by means of the automatic iterative fitting features of the Automated Cross Section Analysis Program (ACSAP). A value of 11.5 b was used for the potential scattering cross section.

ACSAP will upon request print and plot the differences between experimental points and the cross sections calculated from parameters. Such difference outputs were used in constructing the smooth files. In order to maintain proper α values, the deSaussure data were used as much as possible in constructing these different files. However, this ideal had to be abandoned above about 35 eV, as degraded resolution spread the intrinsic difference well away from the resonances to which they apply.

The scattering smooth file represents the difference between the single-level prediction and a multilevel calculation adjusted to minimize the effects of interference imbalance at the two ends of the resolved resonance region.

The parameters plus smooth file yield resonance integrals between 1 and 82 eV of 170.6 and 104.5 b for fission and capture, respectively. The average alpha is 0.613 in this region, compared to a value of 0.617 calculated directly from deSaussure's data.

The root mean square fractional difference between the fit and the individual data sets averages about 3.5%. This figure comes from an analysis of partial resonance integrals from the fit and from the data. Resonance energies are probably good to 0.050 eV and resonance widths to 10%. Overall error in cross sections is about 5%.

For further details see the full report, ANCR-1044.

Unresolved Resonance Region

The ENDF/B-III evaluation in the unresolved energy range is based primarily on the experimental data of deSaussure. At the time of this evaluation, detailed resolution cross sections were not available from the recent measurements of Perez, Blons or Lemley. For this evaluation, a continuous curve of the fission cross section was constructed so as to reproduce the decimal interval averages of the experimental data.

Differences between the present and ENDF/B-II evaluations are due to inclusion of new experimental data, renormalization of the experimental data to recent $^{10}B(n,\alpha)$ cross sections and to differences in methods of constructing a smooth curve. The ENDF/B-III evaluation was obtained by averaging the data of deSaussure over lethargy intervals and by passing a continuous curve through the intervals.

The unresolved resonance parameters in the ^{235}U ENDF/B-III file were modified to yield the evaluated fission cross section and to reproduce the ENDF/B-II alpha value as closely as possible. The parameters were obtained by adjusting the parameters to yield the desired fission and alpha values.

The cross sections which were fitted and the s-wave strength function and fission widths resulting from the fitting procedure are given in WARD-4210T4-1. In this evaluation, the upper energy range for the unresolved resonance parameters was cut off at 25 keV and pointwise data was used above this energy.

Data Above 25 keV

a. Fission Cross Section

Qualitatively, the experimental data in the energy range ~25 keV to 100 keV falls into two groups: the low fission values of Szabo and Lemley which use ^{6}Li as a standard and the higher fission values such as White and DeSaussure which use hydrogen and ^{10}B as a standard. However the recent data of Gwin using a ^{10}B standard supports the low fission values. The data of Blons tend to support the lower fission values while the data of Knoll are in good agreement with White's data. The use of ^{6}Li or ^{10}B as a standard does not appear to be the source of the discrepancy because the ^{10}B cross section used for normalization is partially derived from the ^{6}Li data consistent with Lemley's normalization.

No clear choice based on the differential data can be made at the present time between the low and high fission values. Integral testing against critical assemblies indicates that use of the lower fission values would require major cross section adjustments – particularly very low capture cross sections for ^{238}U in order to obtain eigenvalues as close as 1% less than unity. The latter is particularly true for soft spectrum assemblies typical of interest in LMFBR design. For this reason, the choice for the present evaluation is based on the data of Perez, White and Knoll.

The experimental data for the U^{235} fission cross section above 100 keV, as utilized in the present evaluation is based on the measurements of White, Szabo and Smith as corrected by Hansen. The data of Poenitz indicates notably lower fission values than the other measurements in this energy range. The principal new measurement since the ENDF/B-II evaluation is that of Szabo. The measurements of Kappeler were reported since the present evaluation. The Szabo measurement is the principal source of the differences between the present and ENDF/B evaluations between 0.15 and 1.0 MeV.

Between 1.0 and 10.0 MeV, the only measurements with an accuracy of better than 5% are those of White at 2.25 and 5.4 MeV with relatively poor shape determination in this energy range. In the present evaluation, the U^{235} fission cross section between 1.0 and 10.0 MeV was evaluated within existing uncertainties in order to increase the cross section by 1 to 3% primarily to enhance the U^{238} fission cross section for which the most accurate measurements are relative to U^{235} fission. Above 10 MeV, the present evaluation is evaluated to obtain a 14 MeV cross section of 2.13 barns.

The detailed structure in the U^{235} fission cross section is important as it leads to variations of up to about 3% between groups of multigroup cross sections averaged over quarter lethargy widths typical of many LMFBR calculations and it significantly influences the Pu^{239} fission cross sections derived from ratios of $^{239}Pu/^{235}U$ fission. For the present evaluation, a compromise structure was selected based on the measurements of Perez and Lemley. The evaluated structure was normalized to obtain the 10 keV evaluated average cross section. This structure could possibly be improved when pointwise data from the measurements of Perez and Lemley become available.

b. Capture Cross Section

The capture cross section above 25 keV was obtained by folding the newly evaluated fission cross section into the ENDF/B-II alpha values. Results of discussions with deSaussure (ORNL) relative to the two sets of ORNL alpha data (the lower values of Weston et al. and the higher values of deSaussure, et al.) provided no basis of establishing one data set over the other. A weighted average of the two sets was used. The alpha evaluation is summarized as follows: 15-40 keV (Schmidt evaluation); 40-60 keV (joining of new and Schmidt evaluation); 60-200 keV (5-7% higher than Schmidt evaluation); 200-400 keV (smooth joining of new and Schmidt evaluations); above 400 keV (Schmidt evaluation).

c. Total Cross Section

Above 2 MeV, the data of Glasgow and Foster was used to represent the total cross section. Below 2 MeV the total cross section of MAT 1044 was adopted.

d. Elastic Scattering Cross Section

The elastic scattering cross section was obtained by subtracting from the total cross section the sum of the remaining partial cross sections.

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                         ENDF/B MATERIAL NO= 1045
  U-235RSFP B+W             EVAL=DEC66 W.A.WITTKOPF (FOR THERM,REACTORS)
  BAW-320(DEC,1966)         DIST=JUL68 REV-JUN70
  *          *          *          *          *          *          *
  DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
  *          *          *          *          *          *          *
  THIS DATA SET IS FOR USE IN BURN-UP CALC. FOR THERMAL REACTORS
  *          *          *          *          *          *          *
 U-235 LUMPED FISSION PRODUCT NO.1(LFP1), RAPIDLY SATURATING,
 GENERATED DECEMBER 1966, REFERENCES ARE
 1, W A WITTKOPF, BAW=320, (DEC, 1966), GIVES DETAILS AND METHODS
 2, J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
   OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
 3, N F WIKNER AND S JAYE, GA=2113 (JUNE 1961), GIVES NUCLEAR DATA

   THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL
 FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED
 BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS
      1, THE XE=135 CHAIN
      2, THE SM=149 CHAIN
      3, LFP1 (CD-113, SM-151, GD-155, GD-157)
      4, LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143,
               ND-145, PM-147, SM-152, EU-153)
      5, LFP3 (ALL OTHER FISSION PRODUCTS),

   CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED
 IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO
 BE INFINITELY DILUTE,  THUS, DATA IS SUPPLIED ONLY FOR MF=1,
 MT=451 AND MF=3, MT=27
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92-235-10
SSFP

ENDF/B MATERIAL NO= 1068

U-235SSFP B+W EVAL=DEC66 W.A.WITTKOPF (FOR THERM,REACTORS)
BAW-320 (DEC,1966) DIST=JUL68 REV-JUN70
* * * * * * *
DATA MODIFIED JUNE,1972 TO CONFORM TO ENDF/B-II FORMATS
* * * * * * *
THIS DATA SET FOR THERMAL REACTORS ONLY
* * * * * * *

U-235 LUMPED FISSION PRODUCT NO,2(LFP2), SLOWLY SATURATING,
GENERATED DECEMBER 1966; REFERENCES ARE

1, W A WITTKOPF, BAW-320, (DEC, 1966), GIVES DETAILS AND METHODS
2, J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
  OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3, N F WIKNER AND S JAYE, GA-2113 (JUNE 1961), GIVES NUCLEAR DATA

THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS

1, THE XE-135 CHAIN
2, THE SM-149 CHAIN
3, LFP1 (CD-113, SM-151, GD-155, GD-157)
4, LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143,
   ND-145, PM-147, SM-152, EU-153)
5, LFP3 (ALL OTHER FISSION PRODUCTS),

CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO BE INFINITELY DILUTE, THUS; DATA IS SUPPLIED ONLY FOR MF=1, MT=451 AND MF=3, MT=27

ENDF/B MATERIAL NO= 1069
U-235NSFP B+W EVAL=DEC66 W.A.WITTKOPF (FOR THERM.REACTORS)
BAW-320 (DEC.1966) DIST=JUL68 REV=JUN70
* * * * * * *
DATA MODIFIED JUNE,1972 TO CONFORM TO ENDF/B-II FORMATS
* * * * * * *
THIS DATA SET FOR THERMAL REACTORS ONLY
* * * * * * *

U-235 LUMPED FISSION PRODUCT NO.3(LFP3), NON-SATURATING,
GENERATED DECEMBER 1966, REFERENCES ARE
1. W A WITTKOPF, BAW-320, (DEC. 1966), GIVES DETAILS AND METHODS
2. J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3. N F WIKNER AND S JAYE, GA-2113 (JUNE 1961), GIVES NUCLEAR DATA

THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS

1. THE XE-135 CHAIN
2. THE SM-149 CHAIN
3. LFP1 (CD-113, SM-151, GD-155, GD-157)
4. LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143, ND-145, PM-147, SM-152, EU-153)
5. LFP3 (ALL OTHER FISSION PRODUCTS).

CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO BE INFINITELY DILUTE. THUS, DATA IS SUPPLIED ONLY FOR MF=1, MT=451 AND MF=3, MT=27

ENDF/B MATERIAL NO= 1256

FISSION FRAGMENT RESIDUAL LUMP FOR U-235
PUT IN ENDF/B2 FORMAT BY ZIZO LIVOLSI, BABCOCK-WILCOX, AUG 1971
THIS IS A FICTITIOUS NUCLIDE THAT INCLUDES INTO A SINGLE LUMP ALL
THE FISSION FRAGMENTS FROM U-235 WITH EXCEPTION OF THE 53 NUCLI-
DES EXPLICITELY DESCRIBED IN ENDF/B, WALKER(1) HAS CALCULATED THE
SUM OF THE YIELD X SIGMA AND YIELD X RI, BY NORMALIZING THE SUM
OF YIELDS TO 2

AT 2200M	SIGMA-C =	1.156	BARNS
ENDF DATA TOTAL CAPTURE	INTEGRAL =	5.23	BARNS

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92-U-236 1163 SRL TO BE PUBL. OCT71 F.J.MC CROSSON

ENDF/B MATERIAL NO= 1163
EVALUATION OF U=236, OCT, 1971 (SAVANNAH RIVER LAB)

* * * * * * *

ABOVE 1 KEV THE EVALUATION OF NEUTRON CROSS SECTIONS IS DOCUMENTED BY DRAKE AND NICHOLS IN REPORT GA-8135. BELOW 1 KEV THE NEUTRON CROSS SECTIONS ARE TAKEN FROM MEASUREMENTS BY CARLSON ET AL, REPORTED IN GA=9057.

* * * * * * *

MF= 1 MT=452 NU=2.37+.000000135E (SAME AS U=234) REF.3
MF= 1 MT=453 DECAY DATA TAKEN FROM 1965 CHART OF THE NUCLIDES
MF= 2 MT=151 RESONANCE PARAMETERS TAKEN FROM REF.2
MF= 3 MT= 1 TOTAL CROSS SECTIONS TAKEN FROM REF. 1 AND 4.
MF= 3 MT= 2 ELASTIC CROSS SECTIONS, REF. 1 AND 4.
MF= 3 MT= 4 INELAS. CROSS SECT.,REF. 1 AND 4, Q=VALUE, REF. 5.
MF= 3 MT= 16 (N,2N) CROSS SECT., REF. 1 AND 4, Q=VALUE, REF. 6.
MF= 3 MT= 17 (N,3N) CROSS SECT., REF. 1 AND 4, Q=VALUE, REF. 7.
MF= 3 MT= 18 FISSION CROSS SECT., REF. 1 AND 4, Q=VALUE, REF. 8.
MF= 3 MT=102 (N,GAMMA) CROSS SECTIONS, REF. 1.
MF= 3 MT=251,252,253 CALCULATED BY CHAD
MF= 4 MT= 2 DIFF. ELAST. SAME AS FOR TH=232, REF. 10.
MF= 5 MT= 4 DATA FOR 6 LEVELS PLUS CONTINUUM, REF. 1 AND 4.
MF= 5 MT=16 (N,2N) ENERGY DIST DESCRIBED BY MAXWELLIAN.
MF= 5 MT=17 (N,3N) ENERGY DIST DESCRIBED BY MAXWELLIAN.
MF= 5 MT=18 FISS. NEUTRON ENERGY DIST GIVEN BY SIMPLE FISS. SPECTRUM PLUS MAXWELLIAN.

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92-U-238 1158 WARD TO BE PUBL. AUG71 T.A.PITTERLE AND C.DURSTON

Evaluation of ^{238}U Neutron Cross Sections for the ENDF/B Version III File*

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I. INTRODUCTION

This report describes the U-238 neutron cross section for evaluation for the ENDF/B Version III file, material number 1158. Experimental data available to June, 1971, were included in this evaluation. This evaluation is a major revision of the U-238 Version II data[1] and is very similar to the modified Version II evaluation described by Pitterle, Paik, and Durston[2]. All cross sections above 5.0 eV have been re-evaluated since the Version II evaluation.

This report is divided into four chapters covering evaluations for the resonance parameter in File 2 of the ENDF/B data, the pointivise data in File 3, the secondary angle and energy distributions of Files 4 and 5, and uncertainty estimates for the cross sections.

II. RESONANCE PARAMETER EVALUATION

A. Method of Evaluation for Resolved Resonance Parameters

Heretofore, evaluations have involved weighted means with little emphasis on systematic differences between measurements. An attempt has been made in this evaluation, especially up to 1.0 keV, to reduce systematic differences before calculating means. The method used here is a form of regression analysis where one of the measurements is taken as a standard and the others plotted against it. The quantity plotted was (Γ_n/E) for each resonance, this being a measure of the area of each resonance. Below 1.0 keV, Rohr[5] was taken as the standard and the measurements of Asghar[6], Carraro[4], Rahn[3], and Garg[7] were plotted against this standard.

*Work performed under AEC Contract AT(30-1)4210, Task 4

A least squares fit of the form y=mx was applied, y being the value of (Γ_n/E) from one of the four measurements and x being the standard (Γ_n/E) of Rohr. Ideally, these four lines would lie on top of each other with a slope of 45 degrees. Any deviation from 45 degrees shows a systematic difference and the scatter of points around the line is a measure of the consistency of the experiment. Rohr was chosen as the standard below 1.0 keV since the experiment showed the most consistency with the other experiments.

A mean normalization of each measurement to the reference standard can then be obtained by normalizing the least squares fit of each measurement to the 45 degree reference curve. Table 1 shows the scale factors for each measurement as obtained by this procedure using Rohr and Rahn as the reference data. Scale factors greater than unity thus indicate measurements having neutron widths which, on the average, are greater than those of the reference data. Deviations in the scale factor from unity are a measure of systematic differences between experiments. The values of Γ_n for each measurement have then been normalized by the scale factor given in the table. Other measurements were initially included in this approach, but were discarded because the scatter of the points was judged to be excessive.

Table 1. Scale Factors for Normalization of ^{238}U Resonances

ΔE - keV	Rohr	Asghar	Garg	Rahn	Carraro
0.0 - 1.0	1.0*	0.816	0.974	1.097	1.005
1.0 - 1.5			0.893	1.0*	0.98
1.5 - 2.0			0.838	1.0*	1.008
2.0 - 2.5			0.665	1.0*	1.033
2.5 - 3.0			0.799	1.0*	1.185
3.0 - 3.5			0.740	1.0*	1.375
3.5 - 4.0			0.769	1.0*	1.323

*The values indicated by an asterisk are the reference values used for normalization. The scale factors are the slopes of a least squares straight line passing through the origin and fitting a plot of (Γ_n/E) reference.

The means, variances (σ^2) and standard deviation (σ) were calculated from the scaled experimental values and the reference values. This procedure significantly improved the agreement between the scaled values compared to the agreement between the original measurements. However, this analysis does not give the ultimate scaling, only a relative one.

B. Evaluation of Resolved Resonance Neutron Widths

Using the evaluation method described above, good agreement was found below 1.0 keV between the mean value of the scaled measurements and the data of Carraro. Based on this agreement and general consistency considerations, neutron widths of Carraro were selected for this evaluation below 1.0 keV. The fact that the ENDF/B Version II parameters (based mainly on the Garg data) yielded low capture cross sections compared to measurements of Moxon[8] and de Saussure[9] also contributed to the choice of the Carraro neutron widths up to 1.0 keV. In addition, the Carraro data yielded the best agreement near 700 eV with the measured capture cross sections whereas the other measurements yielded notably lower capture values in this energy range.

The above procedure was repeated above 1.0 keV for the three experiments available, and a list of scale factors relative to the data of Rahn are given in Table 1. These values indicate that there is a large measure of disagreement between 1 and 4 keV. Rahn's neutron widths were chosen for the present evaluation values because of known deficiencies in Garg's values, a reluctance to increase the strength function to that required by the Carraro values and the fact that the Rahn data tend to be a mean between the Garg and Carraro data.

Below 66 eV the s-wave neutron widths were taken from the previous ENDF/B evaluation.

The resonance energies are those of the particular experiments chosen. Garg and Rahn agree well over the whole range and Carraro agrees well up to 1 keV and is only 4 eV different at the higher energies.

C. Evaluation of Resolved Resonance Capture Widths

The correlation method described above was also attempted for radiative capture widths without much success. The lack of correlation indicating that the error must be very large in these experiments. If one envisages a constant s-wave radiative capture width, one would expect measured widths to fluctuate more with increasing energy due to random overlap of p-wave levels enhancing the s-wave capture area. The Rohr capture widths show such a behavior and as these are consistent with the Carraro Γ_n's, the evaluator has chosen them where available. Elsewhere, values of 23.5 mv (not an average but a lower bound consistent with the overlap argument above) have been used, including some resonances where the value of Rohr is lower than this value. The widths of the resonances in 300 to 400 eV interval were increased slightly from Rohr's values to increase the capture area. Also, two of the larger resonances in the range 700 to 800 eV, not reported by Rohr, have had their widths set at 28.5 MeV for similar reasons.

D. Comparisons of Resolved Data with Pointwise Capture Measurements

Using various sets of resolved resonance parameters developed in this evaluation effort, G. de Saussure of Oak Ridge National Laboratory has performed detailed calculations for comparison with high resolution capture cross section measurements[9]. These comparisons have been used in the present evaluation to confirm existence of resonances (mainly p-wave) and relative magnitudes of resonance capture areas. Based on these camparisons, a number of p-wave resonance assignments were modified and some resonance capture areas were increased to improve agreement with the capture measurements.

Using the final evaluated parameters of this evaluation, de Saussure has found that predicted sample size corrections (for multiple scattering and self-shielding) for two sample sizes yield agreement to within 1/2% for the zero sample size corrected cross section. Previous parameter evaluation were only consistent to within 4% for the corrected cross sections.

E. Average Resolved Resonance Spacings and Strength Functions

Table 2 shows some average spacings and strength functions derived from this evaluation. However, probably the only reliable statistic given here is the s-wave strength function of 1.05×10^{-4} $eV^{-1/2}$, which for ^{238}U, is fairly independent of missing resonances and spin assignments. The s-wave spacing <D> depends very much on the spin assignments of borderline levels and can best be described as 20^{+1}_{-2}. The p-wave value for the strength function, S_1, and <D> are unreliable because of overlap with other p-waves and with the s-wave sequence of resonances, as well as uncertainties in the spin assignments between s- and p-waves.

F. Average Resolved Resonance Capture Cross Sections

Table 3 shows a comparison of measured ^{238}U capture cross sections in the resolved energy range with the evaluated contribution broken down into its component parts. The evaluated cross section tends to lie between the Moxon[8] and de Saussure[9] values which were available at time of evaluation except for the 700 to 800 eV interval in which difficulty has been experienced in obtaining a cross section as high as the low Moxon value. Moxon's latest values show a large measure of agreement with this evaluation except for the 700 to 800 eV range.

G. Unresolved Resonance Parameter Evaluation

Unresolved resonance parameters for ^{238}U were obtained by selecting an s-wave strength function and radiation width and adjusting the p-wave strength function to yield the evaluated capture cross section described in Section III-A. Parameters held fixed in the adjustment procedure are:

S-Wave

$S_0 = 1.05 \times 10^{-4} eV^{-1/2}$-Nominal value but varied below 10 keV

$\Gamma_\gamma = 0.0235$ eV

D_0 - 20.0 eV

P-Wave

S_1 - adjusted energy dependent strength function

$\Gamma_\gamma = 0.0235$ eV

$D(\ell=1, J=1/2) = 20.0$ eV

$D(\ell=1, J=3/2) = 10.983$ eV

The radiation width, s-wave strength function and s-wave level spacing are based on the resolved resonance data.

Table 2. Average Resolved Resonance Spacings and Strength Functions for ^{238}U.

ΔE keV	s-wave			p-wave		
	Number Resonances	<D>	$S_0 x 10^4$	Number Resonances	<D>	S_1 x 10^4 R = .84
0- .5	25	20.0	.957	64	7.8	1.652
0-1	50	20.0	1.002	118	8.47	1.511
1-2	48	20.8	1.083	78	7.69	1.009
2-3	53	18.9	1.119	31	*	*
3-4	48	20.8	0.974	31	*	*
0-1.5	74	20.3	.929	164	9.15	1.410
0-2	98	20.4	1.043	196	10.2	1.260
0-3	151	19.9	1.068	227	*	*
0-4	199	20.1	1.045	258	*	*

*not meaningful from present evaluation

Table 3

Comparison of Evaluated and Measured ^{238}U Capture

Cross Sections in the Resolved Energy Range

ΔE keV	Resolved Resonance Contribution s-wave	p-wave	Estimated Background	Net σγ	Measurements Moxon*	DeSaussure	Revised Moxon	ENDF/B Version II
0.0 - 0.1	45.87	.05	0.0	45.92				45.68
0.1 - 0.2	17.65	.07	0.0	17.72				16.39
0.2 - 0.3	8.61	.15	0.0	8.76				8.27
0.3 - 0.4	3.06	.07	0.0	3.13				2.61
0.4 - 0.5	2.49	.17	0.0	2.66				2.34
0.5 - 0.6	4.97	.13	0.0	5.10	4.66	5.38	4.97	4.60
0.6 - 0.7	3.57	.15	0.0	3.72	3.53	4.00	3.75	3.22
0.7 - 0.8	1.71	.21	0.05	1.97	1.79	2.08	2.11	1.61
0.8 - 0.9	3.02	.13	0.05	3.20	3.12	3.30	3.37	2.88
0.9 - 1.0	4.19	.13	0.06	4.38	3.91	4.60	3.64	3.92
1.0 - 2.0	1.60	.15	0.12	1.87	1.82	2.11	1.97	1.85
2.0 - 3.0	1.11	.08	0.21	1.40	1.41	1.58	1.48	1.37
3.0 - 4.0	.87	.11	0.26	1.24	1.19	1.30	1.23	1.23

*Moxon's originally reported measurements with DeSaussure's self-shielding factors.

The nuclear radii for potential scattering is 0.9184×10^{-12} cm and for penetrability calculations is 0.8401×10^{-12} cm. These values and the spin and energy dependence of the level spacing are the same as the ENDF/B Version II evaluation[1]. Similarily, a d-wave background cross section, the same as the Version II evaluation, was included as smooth data in File 3 of the ENDF/B data and considered in adjusting the p-wave strength function to the evaluated data.

Results of the fitting procedure are given in Table 4. Column 5 of Table 4 is the evaluated capture cross section while columns 2 to 4 give the s, p, and d-wave components. Columns 6 and 7 give the s- and p-wave strength functions while column 8 is the J=1/2 level spacing. At a few energies in Table 4, the s-wave strength function was varied about the nominal value of $1.05 \times 10^{-4} eV^{-1/2}$. The low s-wave strength functions between 4.0 and 5.0 keV are indicated by the resolved resonance data of Rahn[3] and Carraro[4].

Table 4. Unresolved Resonance Parameters and Cross Sections for ^{238}U

Energy (keV)	σ_γ				Adjusted $S_\ell \times 10^4 (eV^{-1/2})$		J=1/2 Level Spacing
	S-Wave	P-Wave	D-Wave	Net	S_0	S_1	
4.000	0.714	0.296	0.0	1.010	0.90	1.337	20.00
4.500	0.653	0.335	0.0	0.988	0.95	1.496	19.98
5.500	0.567	0.413	0.0	0.980	1.12	1.850	19.95
6.500	0.487	0.426	0.0	0.913	1.10	1.877	19.92
7.500	0.425	0.404	0.0	0.829	1.05	1.718	19.88
8.500	0.376	0.373	0.0	0.749	1.00	1.518	19.84
9.500	0.344	0.319	0.002	0.745	1.05	1.671	19.80
12.000	0.280	0.415	0.005	0.700	1.05	1.807	19.71
15.000	0.229	0.411	0.007	0.647	1.05	1.932	19.61
20.000	0.177	0.373	0.010	0.560	1.05	1.781	19.44
25.000	0.145	0.344	0.014	0.503	1.05	1.809	19.26
30.000	0.124	0.318	0.018	0.442	1.05	1.754	19.09
35.000	0.108	0.300	0.023	0.431	1.05	1.720	18.92
40.000	0.096	0.282	0.027	0.405	1.05	1.776	18.75
45.000	0.087	0.264	0.032	0.383	1.05	1.806	18.59

III. CROSS SECTION EVALUATIONS

A. Capture Cross Section Above 4 keV

Recent capture cross section measurements have been reported by de Saussure[9] below 100 keV and by Fricke[10] between 1 and 700 keV. Since the present evaluation was completed, corrections to the 1969 measurements of Moxon[8] have become available. These data, along with measurements by Menlove[11], Poenitz[12,13], Barry[14], Belanova[15] as corrected by Miller[16], de Saussure[17], and Gibbons[18] are compared with evaluated data in Figure 1.

The present evaluation between 4 and 100 keV is based on an average of the data of de Saussure[9] and Moxon[8]. This procedure leads to only a slight change in shape from the ENDF/B Version II data[1]. The 30 keV capture cross section of 0.46 barns in the present evaluation is consistent with an average of all experimental data at or near 30 keV. Consequently, the average of the Moxon and de Saussure data can be viewed as using the shape determination of these data and normalizing this shape to the average of the 30 keV measurements.

The available experimental data above 100 keV tend to fall into two groups: high capture cross sections obtained from combining ^{238}U capture/^{235}U fission ratio measurements by Poenitz[12], and Barry[14] with the ^{235}U ENDF/B Version III fission cross section; and low capture cross sections obtained from absolute measurements of Fricke[10] or the data of Menlove[11]. No clear choice can be made between the high or low values based only on an assessment of the measurements. Agreement between calculations and critical experiment measurements tends to be significantly improved[Ref.2] using the low capture data above 100 keV. For this reason, the present evaluation was based primarily on the data of Fricke[10] above 100 keV.

B. Fission Cross Section

Integral testing with the ENDF/B Version II data indicated the ENDF/B ^{238}U fission cross section is about 4 to 8 percent too low. The average of the ENDF/B fission cross section over a ^{235}U thermal fission spectrum is 0.284 barns compared to measured values between 0.30 and 0.31 barns.[19]

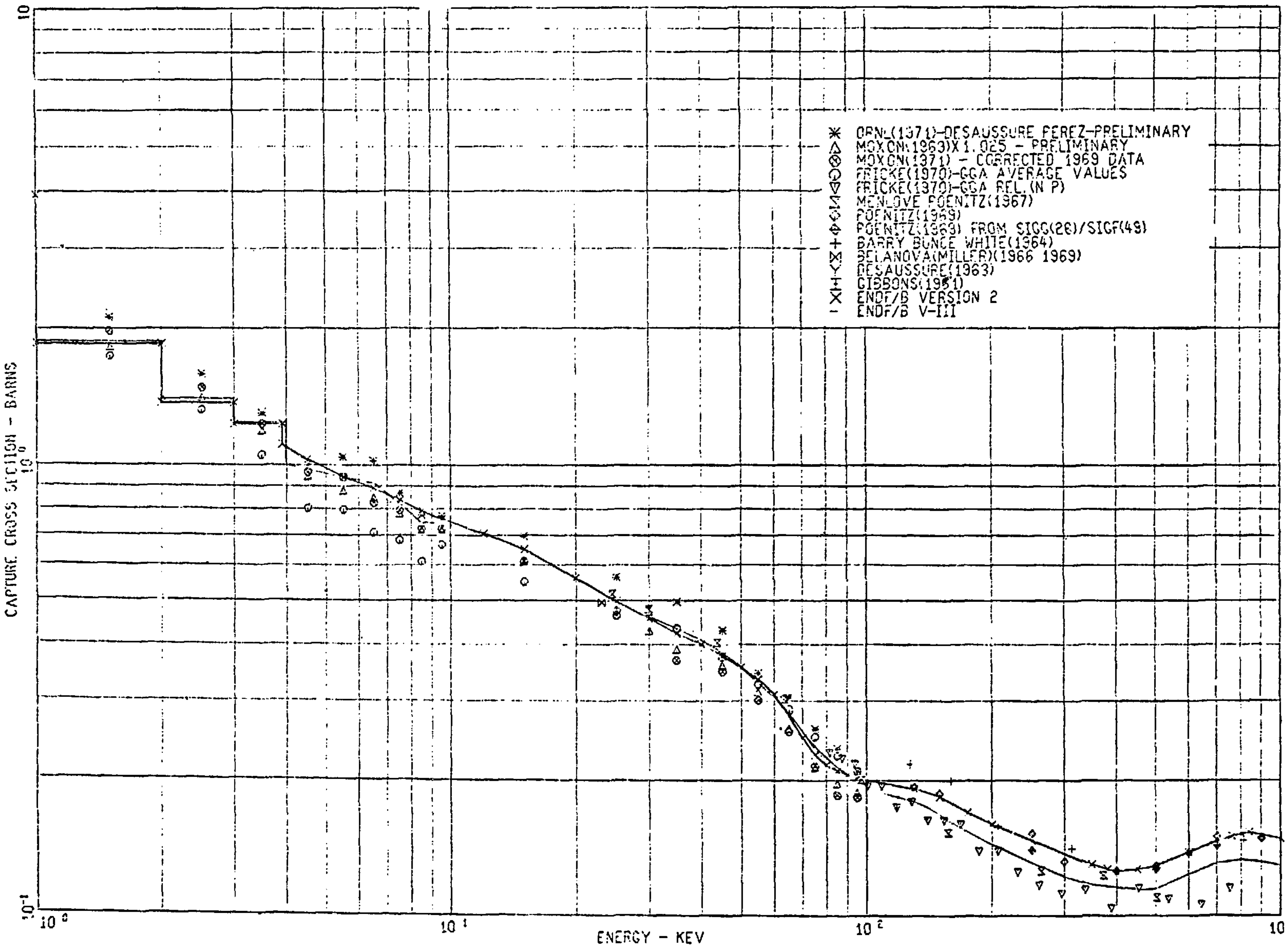

Figure 1. Comparison of Experiment and Evaluation for U-238 Capture

For the present evaluation, the ^{238}U fission cross section was increased by 4 to 5 percent below 7 MeV to obtain a ^{235}U fission spectrum average of 0.298 barns. The present evaluations for the $^{238}U/^{235}U$ fission ratio and the ^{238}U fission cross section are compared with experimental data and the ENDF/B evaluation in Figure 2. The modified $^{238}U/^{235}U$ fission ratio is about 2% lower than the data of Lamphere[20] below 2.0 MeV and about 5 percent higher than the measurements of Stein[21] between 2 and 5 MeV. Other data considered in the evaluation are those of Hansen[22], White and Warner[23], Jarvis[24], Nyer[25], Moat[26], Uttley[27], and Adams[28].

A subthreshhold measurement by Silbert[29], which indicates an average ^{238}U fission cross section of about 40 microbarns between 10 and 100 keV, has been included in the present evaluation below 400 keV.

C. Inelastic Scattering Cross Section

No major changes were made to the inelastic scattering cross section of ENDF/B Version II[1]. Minor changes were made to harden the secondary energy distribution in order to improve agreement between calculations and integral experiment measurements[2]. In the present evaluation, resolved levels were extrapolated to 2.0 MeV or higher and four estimated levels at 1.50, 1.60, 1.70, and 1.80 MeV were added to match the 2.0 MeV distribution of Batchelor[30]. These levels replace a statistical distribution between 1.55 and 2.0 MeV in the Version II evaluation.

Slight modifications were also made to the resolved level cross sections below 2.0 MeV to produce a somewhat harder secondary spectrum while maintaining essentially the same total inelastic cross section as the ENDF/B data.

The evaluated inelastic scattering cross section is completely resolved up to 2.0 MeV with a statistical distribution beginning at this energy and representing the total inelastic cross section above 3.5 MeV. Above 2.0 MeV, the inelastic cross section is obtained as the difference between the evaluated nonelastic cross section and the sum of the partial reaction cross sections for capture, fission, (n,2n) and (n,3n).

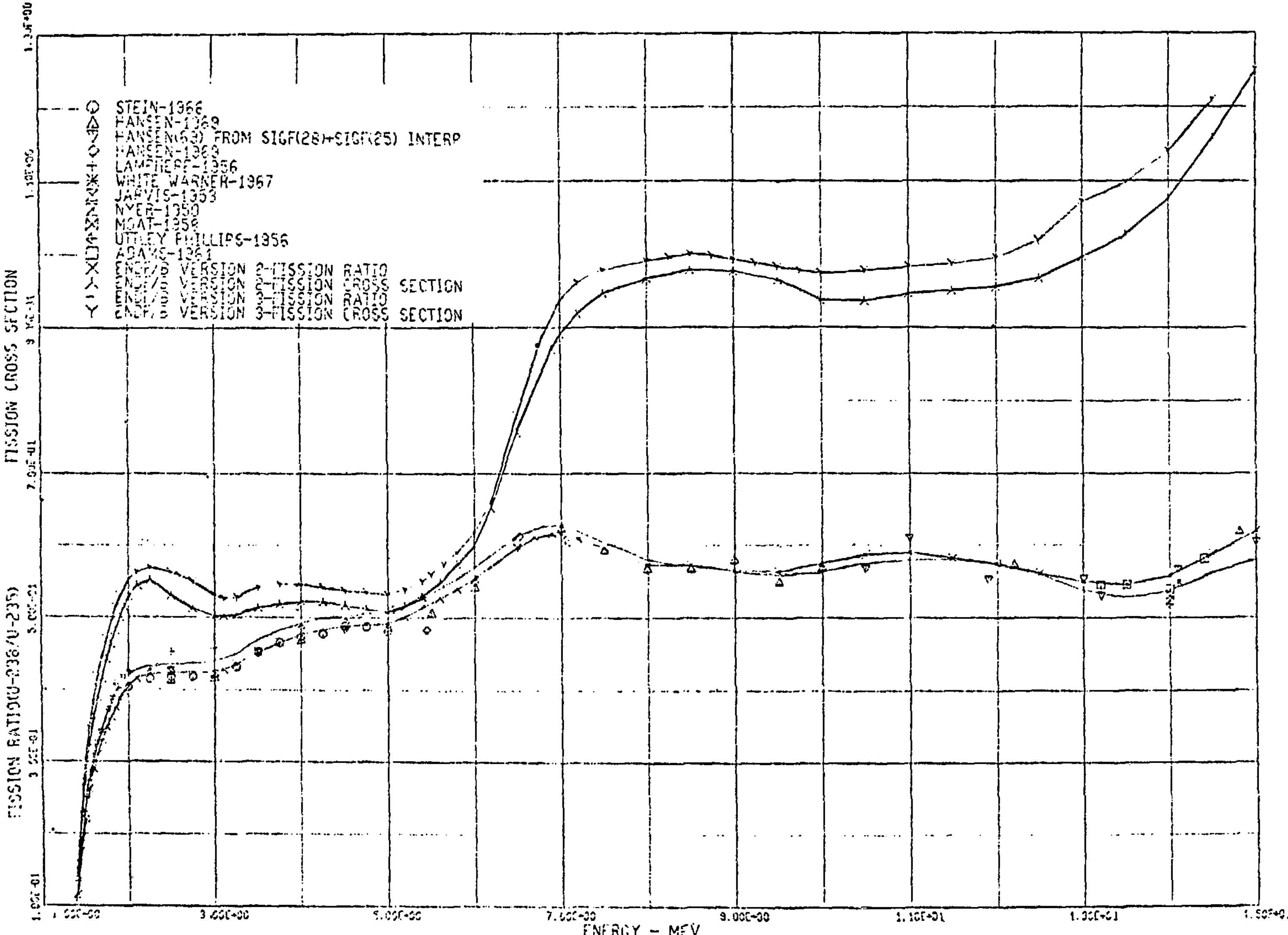

Figure 2. Comparison of Experiment and Evaluation for U-238 Fission

D. Total Cross Section

Recent measurements of the ^{238}U total cross section by Kopsch[31] and Cabe[32] between 0.5 and 6.0 MeV indicate total cross sections a few percent higher than the ENDF/B Version II evaluaton[17]. These measurements were included in the present evaluation leading to an increase of about 2% in the total cross section.

E. (n,2n), (n,3n) Cross Sections

The (n,2n) cross section for this evaluation used the ratio of ^{238}U (n,2n)/fission of the Version II evaluation combined with the present evaluation for ^{238}U fission to obtain the (n,2n) cross section. This procedure was used as no new measurements have been reported since the Version II evaluation and the reported experimental data for (n,2n) were measurements relative to ^{238}U fissions.

The (n,3n) evaluation is based on the 14 MeV value of Mather[33] with an estimated shape for the cross section.

F. Nonelastic Cross Section

The nonelastic cross section up to 2.0 MeV was obtained as a summation of the evaluated capture, fission and inelastic scattering cross sections. A 2.0 MeV value of 3.37b was obtained based primarily on the evaluated total cross section of 7.21b and Batchelor's[30] measured elastic scattering cross section of 4.07b which included inelastic scattering (estimated as 0.2b in present evaluation) from the first two levels. Above 2.0 MeV, the present evaluation includes only minor shape modifications of the Version II evaluation.

G. Elastic Scattering Cross Section

The cross section for elastic scattering was obtained as the difference between the evaluated total and nonelastic cross sections.

H. Cross Sections Below 5.0 eV

The ENDF/B Version II evaluation for cross sections below 5.0 eV, which is based on an evaluation by Leonard[34], was retained for the present evaluation.

I. $\bar{\nu}$ - NUMBER OF NEUTRONS PER FISSION

The average number of neutrons per fission was re-evaluated based primarily on the measurements of Soleilhar[35] for the prompt neutrons per fission. Normalization of the data was based on $\bar{\nu}$ of ^{252}Cf - 3.765 from the IAEA evaluation[36]. The number of delayed neutrons per fission, ν_d, used in this evaluation is 0.0444 based on an evaluation by Stewart and Hansen[37] of the data of Keepin[38] and Masters[39]. The energy dependence of ν_d was obtained by normalizing the energy dependent measurements of Krick and Evans[40] to 0.0444 at 3.0 MeV. A tabulated energy dependence is given for the total number of neutrons per fission in the ENDF/B file.

IV. SECONDARY ANGULAR AND ENERGY DISTRIBUTIONS

A. Angular Distributions for Elastic Scattering

Angular distributions were evaluated at 27 energies between 10^{-5} eV and 15 MeV by fitting Legendre polynomial expansions in the center of mass systems to the experimental data. Below 10 keV, the distributions are evaluated as isotropic scattering in the center of mass system. The present evaluation is based largely on experimental data reported in BNL-400[41] along with calculations by Prince[42] above 3.0 MeV.

The most significant measurements influencing the present evaluation are: 0.075, 0.157, and 0.25 MeV - Barnard[43] and Lane[44]; 0.30 MeV - Smith[45] and Korgh[46]; 0.41 MeV - Barnard[43] and Smith[45]; 0.55 MeV - Smith[45], Barnard[43] and Korzh [46]; 0.68 MeV - Smith[45]; 0.83 MeV - Smith[45], Elwin[47], Korzh [46] and Barnard[43]; 1.0 MeV - Smith[45], Allen[48], Walt[49] and Gilboy[50]; 1.25, 1.50 MeV - Smith[45]; 2.0 MeV - Batchelor[30] and Cranberg[51], 2.5 MeV - Walt[52]; 3.0, 4.0 MeV - Batchelor[30] and Prince[42]; 5.0 MeV - Prince[42] and Buccino[53]; 7.0 MeV - Batchelor[30], Walt[52] and Prince[42], 8.0, 10.0 MeV - Prince[42]; 14.1 MeV - Coon[54], and Prince[42]; 15.0 MeV - Guzhovski[55] and Prince[42].

The angular distributions for 0° scattering were evaluated to be consistent with Wick's limit, $d\sigma/d\Omega(\theta=0°) = k^2\sigma_t^2/(4\pi)^2$, as the lower limit for the cross section. Measured angular distributions below 2.0 MeV were corrected for inelastic scattering (assumed to be isotropic) before fitting the data with Legendre expansions.

B. Statistical Inelastic Scattering Energy Distribution

As noted in the Version II report[1], the secondary energy distributions at 2.0 MeV, as measured by Batchelor[30], is not well described by a statistical distribution. An increase in the nuclear temperature for the statistical distribution from the Version II value of 0.291 MeV to 0.35 MeV improves slightly the fit to Batchelor's distributions although the fit still is not particularly good. Comparisons of calculations and integral measurements tend to support a somewhat harder secondary energy distribution for inelastic scattering. For these reasons, a nuclear temperature of 0.35 MeV at 2.0 MeV was chosen for the present evaluation. This temperature was then extrapolated to agree with the ENDF/B value at 8.0 MeV.

C. Secondary Energy Distributions for Fission, (n,2n) and (n,3n)

The fission spectrum is specified as an neutron energy dependent simple fission spectrum with nuclear temperatures of 1.31, 1.34, and 1.53 MeV at 1.0, 2.5, and 15.0 MeV, respectively. Secondary energy distributions for (n, 2n) and (n, 3n) are Maxwellian distributions retained from the Version II evaluation.

IV. ESTIMATES OF DATA UNCERTAINTIES

Based on differences between reported measurements, the following estimates of uncertainties for the data in the present evaluation are made:

1. Resonance Parameters

Resolved Γ_n after normalization + $\pm$5% 0 to 1 keV, $\pm$ 10 to 1 to 4 keV/

$\langle\Gamma_\gamma\rangle = 23.5 \pm 2$ mv

$S_o = 1.05 \pm 0.1 \times 10^{-4}$ eV$^{-1/2}$

$\langle D_o\rangle = 20.0\ ^{+1.0}_{-2.C}$ eV

$S_1 = 1.7 \pm 0.6 \times 10^{-4}$ eV$^{-1/2}$

2. Pointwise Cross Sections

σ_γ - $^{+8\%}_{-5\%}$ < 4 keV, $^{+8}_{-12\%}$ 4 to 100 keV, $^{+10\%}_{-5\%}$ above 100 keV

$\sigma_f^{28}/\sigma_f^{25}$ - ± 6% < 2 MeV, $^{+3\%}_{-5\%}$ 2 to 5 MeV, ± 6% above 5 MeV.

σ_f - 5 to 10% over entire energy range

σ_{in} - $^{+8\%}_{-5\%}$ below 1 MeV, 5 - 10% between 1 and 6 MeV, 10-15% between 6 and 12 MeV, 50% above 12 MeV

σ_t - ± 3 to 5% over entire energy range

$\sigma_{n,2n}$ - ± 10% except near 14 MeV where accuracy may be ± 5%

$\sigma_{n,3n}$ - ± 10% over entire energy range

σ_{ne} - ± 10% between 2 and 4 MeV, 5 to 10% above 4 MeV

σ_{el} - ± 5% below 1.5 MeV, 5 to 10% above 1.5 MeV

$\bar{\nu}$ - 2 to 3%

These uncertainties in the ^{238}U data, particularly for capture and fission cross sections, do not neet the accuracy requirements of a few percent for σ_γ and σ_f that are required for reliable fast reactor analysis.

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93-NP-237 1145 BNW TO BE PUBL. MAY69 B.R.LEONARD

Np-237

A complete reevaluation of the ^{237}Np cross section to energies of 15 MeV was made. The previous BNWML version was inadequate and the original ENDF/B version(5) contained several bad estimates. The results of the present evaluation of the most importance to the present function are summarized here.

No satisfactory existing evaluation of the thermal cross section could be found. The previous BNWML version prescribed a 1/v behavior of the capture cross section. The ENDF/B version(5) increased faster than 1/v by about five percent. The ENDF/B evaluation stated that the only existing energy dependent total cross section data below 0.1 eV were due to a MTR crystal spectrometer measurment of Smith, et. al.(6) Actually, a later set of measurements was made at the MTR by Cline, et al.(7) and these measurements were considered by the Director of that program to supersede the earlier measurements of Smith, et. al.(8) In addition, total cross section data in the thermal range were presented by a Russian group(9) at the Geneva Conference. Strangely, neither the thermal data of Cline, et. al. or the Russian data have ever appeared in any of the issues of(10) BNL-325 although both are cited in CINDA.(11) The data of Cline, et. al. show a decrease from 1/v of some 30 percent in the thermal region. The Russian data show a somewhat larger decrease and a cross section value some 60 percent larger than the Cline data. Since the absolute values of the Cline data are more consistent with integral measurements these data were fitted to obtain the thermal cross-section shape in this evaluation. The fit required the addition of two negative-energy resonances and gives a 2200 m/s capture cross section of 169 barns. The uncertainty of the value and shape of the thermal cross section is about ± 10 percent which is the accuracy quoted[8] for the data of Cline, et al.

All of the unmeasured partial cross sections for high energy neutrons given in the ENDF/B evaluation were based on an optical-model calculation by Goldman.[12] However, the ENDF/B evaluators interpreted the total non-elastic cross section calculated by Goldman as the neutron inelastic scattering cross section. Thus an extensive revaluation of the high-energy cross section was required. Of most importance to the present function was the evaluation of the n, 2n cross section which leads to the highly radio-active contaminant ^{236}Pu. The presently evaluated n, 2n cross section is based on the statistical calculation of Pearlstein[13] which was used in the original ENDF/B evaluation.[5] However, in the present evaluation Pearlstein's values have been adjusted for competition with other partial processes and rescaled to better agree with a single measured value at 14.5 MeV.[14]

Since the present evaluation, more extensive data in the resolved resonance region has become available and this region should be reevaluated.

CROSS SECTION REFERENCES

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94-PU-238 1050 AI NAA-SR-12271(1967) MAY67 H.ALTER AND C.DUNFORD

ENDF/B MATERIAL NO= 1050
PU-238 AI EVAL-MAY67 ALTER AND DUNFORD
NAA-SR-12271(MAY,67) DIST-JUL68 REV-APR70
* * * * * *
DATA MODIFIED FOR ENDF/B-II FORMATS (APRIL 1970)
* * * * * *
PLUTONIUM-238 REVISED JULY 14,1967

EVALUATED BY ATOMICS INTERNATIONAL
DOCUMENTATION - NAA-SR-12271 MAY 1,1967 + SUPP. 1, JULY 14,1967

MF=1 GENERAL INFORMATION
MT=452 NUBAR NO EXPERIMENTAL DATA AVAILABLE. CORRELATION OF REFERENCE 1 IS USED.
MT=453 RADIOACTIVE DECAY DATA ALL MASSES AND DECAY CONSTANTS FROM REF. 2.

MF=2 RESONANCE PARAMETERS
MT=151 RESOLVED RESONANCES PARAMETERS FOR 14 SINGLE-LEVEL RESONANCES ARE GIVEN (REF. 3). FISSION WIDTHS DEDUCED FROM DATA OF REF. 4. POTENTIAL SCATTERING OF 10.89 BARNS BASED ON DEFORMED OPTICAL MODEL.
UNRESOLVED RESONANCES AVERAGE RESONANCE PARAMETERS OBTAINED FROM RESOLVED RESONANCES AND DEFORMED OPTICAL MODEL.
THIS DATA GIVES A RESONANCE INTEGRAL OF 169.1 BARNS IN GOOD AGREEMENT WITH 160 BARNS MEASURED (REF. 5).

MF=3 SMOOTH CROSS SECTIONS
MT=1 TOTAL CROSS SECTION THERMAL REGION OBTAINED FROM RESONANCE PARAMETERS. 2200M/S VALUE 583.47B COMPARED TO 590 REPORTED IN REF. 6. FAST REGION FROM DEFORMED OPTICAL MODEL(DOM).
MT=2 ELASTIC SCATTERING DATA OBTAINED IN PROCEDURE IDENICAL TO MT=1.
MT=4 INELASTIC SCATTERING DATA RESULTS FROM THE SCATTERING TO 9 LEVELS PLUS CONTINUUM. AGAIN A DOM IS USED WITH A STATISTICAL COMPOUND NUCLEUS MODEL.
MT=16 N,2N CALCULATION BASED ON EVAPORATION MODEL (REF. 7).
MT=17 N,3N SAME AS MT=16
MT=18 FISSION THERMAL REGION DATA CALCULATED FROM RESONANCE PARAMETERS. 2200M/S VALUE IS 16.29B COMPARED TO THE MEASURED VALUE OF 16.6B (REF. 8). FAST REGION DATA CALCULATED FROM COMPOUND NUCLEUS THEORY USING THE HILL-WHEELER MODEL(REF. 9). DATA AGREES WITH RECENT MEASUREMENTS FROM LASL(REF. 10), BUT ARE 20 PERCENT LOWER THAN EARLIER MEASUREMENTS AT 1.0 MEV(REF. 11).
MT=102 CAPTURE THERMAL DATA CALCULATED FROM RESONANCE PARAMETERS. 2200M/S VALUE IS 546.5B. FAST REGION DATA FROM A STATISTICAL MODEL ASSUMING DIPOLE RADIATION.
MT=251 MUBAR CALCULLATED FROM DOM ANGULAR DISTRIBUTIONS
MT=252 XIBAR CALCULLATED FROM DOM ANGULAR DISTRIBUTIONS
MT=253 GAMMA CALCULLATED FROM DOM ANGULAR DISTRIBUTIONS

MF=4 LEGENDRE POLYNOMIALS

MT=2 ELASTIC SCATTERING LEGENDRE COEFFICINTS FOR 15TH ORDER FIT TO CALCULATED ANGULAR DISTRIBUTIONS (DOM) ARE PROVIDED BETWEEN 10 KEV AND 11 MEV AND 19TH ORDER BETWEEN 12 AND 15 MEV.

MF=5 SECONDARY ENERGY DISTRIBUTIONS

ENDF/B MATERIAL NO= 1050

MT=2 INELASTIC SCATTERING CALCULATED DATA FOR 9 LEVELS PLUS CONTINUUM, DIRECT SCATTERING FOR THE FIRST EXCITED LEVEL FROM THRESHOLD TO 15MEV PLUS COMPOUND NUCLEUS SCATTERING TO 3 MEV FOR ALL LEVELS IS INCLUDED, CONTINUUM INELASTIC SCATTERING IS GIVEN BY A MAXWELLIAN WITH AN ENERGY DEPENDENT TEMPERATURE CALCULATED FROM REF. 7.

MT=16 N,2N NUCLEAR TEMPERATURE WITH ENERGY DEPENDENCE AS IN REFERENCE 12.

MT=17 N,3N NUCLEAR TEMPERATURE WITH ENERGY DEPENDENCE AS IN REFERENCE 12.

MT=18 FISSION MAXWELLIAN WITH CONSTANT TEMPERATURE FROM CORRELATION OF REF. 13.

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94-PU-239 1159 GE.BNW.ANC BNWL-1586.ANCR-1045 AUG71 PRINCE.LEONARD.SMITH.PITTERLE

ENDF/B MATERIAL NO= 1159
PU-239 GE,WARD,ANC EVAL=AUG71 LEONARD(BNW),J.R.SMITH(ANC)
ENDF-162,ENDF-153 DIST=JAN72 PAIK,PITTERLE,DURSTON(WARD) +BNL
* * * * * *

PLUTONIUM-239

* * * * *

LOW ENERGY CROSS SECTIONS (1.0-05 EV TO 1.0 EV) EVALUATED BY
B.R.LEONARD, JR. (BATTELLE-PACIFIC NORTHWEST LAB.)
BNWL-1586 (ENDF-153) JUNE 1971

* * * * *

RESOLVED RESONANCE REGION (1.0 TO 300.0 EV) EVALUATED BY
J.R.SMITH (AEROJET-IDAHO NUCLEAR CORP)

* * * * *

UNRESOLVED RESONANCE PARAMETERS EVALUATED BY T.A.PITTERLE,
N.C.PAIK, AND C.DURSTON (WESTINGHOUSE ADVANCED
REACTOR DIV.
FAST NEUTRON FISSION AND RADIATIVE CAPTURE CROSS SECTION BASED
ON DATA BY T.A.PITTERLE AND N.C.PAIK (PROC.CONF.NEUTRON X/S
AND TECH.,KNOXVILLE, 3/71) 300 EV TO 15 MEV

* * * * * *

FISSION PRODUCT YIELD DATA BASED ON EVAL. BY M.E.MEEK AND
B.F.RIDER, YIELDS NORMALIZED TO SUM TO 2.000
APED-5398-A (REVISED) OCT. 1968.

* * * * *

FAST NEUTRON CROSS SECTIONS (ABOVE 25 KEV) EVALUATED BY
A.PRINCE (BNL)

* * * * *

THE PU-239 EVALUATION IN THE ENERGY RANGE OF 8.0 KEV TO 20.0 MEV
WERE CARRIED OUT AT BNL BY A.PRINCE AND M.K.DRAKE.
GENERAL DESCRIPTION
THE TOTAL,SHAPE ELASTIC,TOTAL REACTION AND DIRECT INELASTIC CROSS
SECTIONS WERE CALCULATED USING THE COUPLED CHANNEL CODE JUPITOR 1
(ORNL-4152,T.TAMURA)
THE COMPOUND NUCLEUS REACTION CROSS SECTIONS WERE CALCULATED
WITH THE COMNUC CODE (AI-AEC-12931,C.L.DUNFORD),FISPRO (CEC(69)24
CNEN,V.BENZI ET AL) AND CODE THRESH (TO BE PUBLISHED S.PEARLSTEIN
BNL)
ANGULAR DISTRIBUTION DATA WAS ANALYZED WITH CODE CHAD (NAA-SR-
11231, R.F.BERLAND)
THE RESULTS FROM THE DEFORMED NUCLEUS CALCULATIONS WERE COMBINED
IN A CONSISTENT MANNER WITH THE COMPOUND NUCLEUS REACTIONS TO
OBTAIN ESTIMATES OF ALL PARTIAL NEUTRON CROSS SECTIONS.
FILE 3
COMPLETE DETAILS OF THE CALCULATIONS FOR MT=1,2,4,18,51 TO 91,102
251,AND 252 ARE GIVEN IN PROC. OF THIRD CONF. ON NEUTRON CROSS
SECTIONS AND TECHNOLOGY USAEC CONF. 710301, VOL 1,BY A.PRINCE AND
M.K.DRAKE.
THE PENETRABILITIES USED IN DESCRIBING THE COMPOUND ELASTIC AND
INELASTIC CROSS SECTIONS FOR THE 8.0 KEV AND 57.0 KEV LEVELS WERE
TAKEN FROM THE COUPLED CHANNEL CALCULATIONS, WHILE THE 22 HIGHER
LEVELS WERE DESCRIBED BY THE PENETRABILITIES DERIVED FROM A
SPHERICAL POTENTIAL MODEL CALCULATION.
ELEVEN TRANSITION STATES WERE ASSUMED FOR THE CALCULATION OF THE
FISSION CROSS SECTIONS IN THE DISCRETE REGION WHICH WERE
INTERPRETED IN TERMS OF THE HILL-WHEELER MODEL WITH A CUTOFF
ENERGY OF 0.2 MEV FOR THE CONTINUUM.
THESE CALCULATIONS ALONG WITH THE COMPETITIVE REACTIONS
(INELASTIC, CAPTURE AND COMPOUND ELASTIC) WERE READJUSTED SO AS
TO LEAVE THE FISSION AND CAPTURE CROSS SECTIONS AS(RECOMMENDED BY

T.A. PITTERLE ET AL PROC.OF THIRD CONF ON NEUTRON CROSS SECTIONS
AND TECHNOLOGY USAEC CONF 710301 VOL 1) UNCHANGED
IN THE HIGH ENERGY REGION, BOTH DIRECT AND SEMIDIRECT
CONTRIBUTIONS TO THE CAPTURE CROSS SECTION WERE OBTAINED FROM
FISPRO
THE TOTAL ELASTIC CROSS SECTION (MT=2) IS THE SUM OF THE SHAPE
AND COMPOUND ELASTIC COMPONENTS
THE TOTAL INELASTIC (MT=4) IS THE SUM OF THE TOTAL COMPOUND
INELASTIC AND THE DIRECT INELASTIC SCATTERING CROSS SECTIONS OF
THE 8.0 KEV AND 57.0 KEV LEVELS
MT=51,52 AND 91 (DISCRETE AND CONTINUUM INELASTIC) ALSO
CONTAINS THE DIRECT AS WELL AS THE COMPOUND NUCLEUS COMPONENTS
THE INELASTIC ANGULAR DISTRIBUTIONS ARE ASSUMED TO BE ISOTROPIC
MT=16,17,103,104,105 AND 107 ARE BASED ON CALCULATIONS
RESULTING FROM PROG. THRESH.
THE BINDING ENERGY AND THRESHOLDS ARE BASED ON THE RECENT
ANALYSIS OF A.H.WAPSTRA AND N.B.GOVE AT ORNL AND TABULATED IN
UCRL-50400 VOL 1,1970 F.J.HOWERTON.

* * * * *

RESOLVED RESONANCE PARAMETERS PLUS FILE 3 CONTRIBUTION DESCRIBE
THE CROSS SECTIONS BETWEEN 1 AND 301 EV. PARAMETERS ARE FROM A
SIMULTANEOUS FIT TO TOTAL, FISSION AND CAPTURE CROSS SECTIONS.
DATA FIT ARE THOSE OF GWINS (1) AND DERRIEN AND BLONS (2).
PARAMETERS WERE DERIVED BY O.D. SIMPSON AND F.B. SIMPSON
AEROJET (IDAHO) NUCLEAR CO. AUGUST 1971. A POTENTIAL SCATTERING
CROSS SECTION OF 10.2 BARNS WAS USED. FILE 3, MT=2, CONTAINS
THE SCATTERING SMOOTH FILE. THE FOLLOWING EQUATION WAS USED TO
COMPENSATE FOR THE TAILS OF OSTANCE RESONANCES)
SIGMA SCATT = -.01375*(ENERGY) + 2.2 BARNS. IN THE REGION OF
1 TO 5 EV THERE WAS AN ADDITIONAL SCATTERING CROSS SECTION (LESS
THAN 1 BARN) ADDED TO BLEND THE THEORETICAL SCATTERING CROSS
SECTION ABOVE 1 EV INTO THE SMOOTH FILE BELOW 1 EV. GWINS FISSION
AND CAPTURE DATA WERE NORMALIZED BY HIM TO THE ENDF/B SMOOTH
FILE BELOW 1 EV. THIS NOMALIZATION WAS CHECKED BY US AND FOUND
TO BE IN EXCELLENT AGREEMENT. THE FISSION DATA OF BLONS WERE
NORMALIZED TO GWINS DATA BY USING A MULTIPLICATION CONSTANT OF
0.9415.
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PU-239 WARD MODIFICATION TO ENDF/B MATERIAL NUMBER 1104-MAR.1971
REFERENCE REPORT - WARD 4210-1 (PUBLISHED ABOUT MAY 1971)
MODIFICATIONS PERFORMED BY T.A. PITTERLE, N. C. PAIK
MODIFIED DATA ARE CAPTURE AND FISSION CROSS SECTIONS AND
UNRESOLVED RESONANCE PARAMETERS

ENDF/B MATERIAL NO= 1052
PU-239RSFP B+W EVAL=DEC66 W.A.WITTKOPF(FOR THERM. REACTORS)
BAW-320 (DEC.1966) DIST=JUL68 REV-JUN70
* * * * * * *
DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
* * * * * * *
THIS DATA SET IS FOR USE IN BURN-UP CALC. FOR THERMAL REACTORS
* * * * * * *
PU-239 LUMPED FISSION PRODUCT NO.1(LFP1), RAPIDLY SATURATING.
GENERATED DECEMBER 1966. REFERENCES ARE
1. W A WITTKOPF, BAW-320, (DEC. 1966), GIVES DETAILS AND METHODS
2. J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3. N F WIKNER AND S JAYE, GA-2113 (JUNE 1961), GIVES NUCLEAR DATA

THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS

1. THE XE-135 CHAIN
2. THE SM-149 CHAIN
3. LFP1 (CD-113, SM-151, GD-155, GD-157)
4. LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143, ND-145, PM-147, SM-152, EU-153)
5. LFP3 (ALL OTHER FISSION PRODUCTS).

CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO BE INFINITELY DILUTE. THUS, DATA IS SUPPLIED ONLY FOR MF=1, MT=451 AND MF=3, MT=27

ENDF/B MATERIAL NO= 1070
PU-239SSFP B+W EVAL-DEC66 W.A.WITTKOPF (FOR THERM.REACTORS)
BAW-320 (DEC.1966) DIST-JUL68 REV-JUN70
* * * * * * *
DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
* * * * * * *
THIS DATA SET FOR THERMAL REACTORS ONLY
* * * * * * *

PU-239 LUMPED FISSION PRODUCT NO.2(LFP2), SLOWLY SATURATING,
GENERATED DECEMBER 1966, REFERENCES ARE

1, W A WITTKOPF, BAW-322, (DEC, 1966), GIVES DETAILS AND METHODS
2, J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3, N F WIKNER AND S JAYE, GA-2113 (JUNE 1961), GIVES NUCLEAR DATA

THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS

1, THE XE-135 CHAIN
2, THE SM-149 CHAIN
3, LFP1 (CD-113, SM-151, GD-155, GD-157)
4, LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143, ND-145, PM-147, SM-152, EU-153)
5, LFP3 (ALL OTHER FISSION PRODUCTS),

CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO BE INFINITELY DILUTE. THUS, DATA IS SUPPLIED ONLY FOR MF=1, MT=451 AND MF=3, MT=27

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                         ENDF/B MATERIAL NO= 1071
 PU-239NSFP    B+W      EVAL=DEC66 W.A.WITTKOPF (FOR THERM,REACTORS)
 BAW-320 (DEC,1966)     DIST=JUL68 REV-JUN70
 *        *         *         *         *         *         *
 DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
 *        *         *         *         *         *         *
 THIS DATA SET FOR THERMAL REACTORS ONLY
 *        *         *         *         *         *         *
PU-239 LUMPED FISSION PRODUCT NO.3(LFP3), NON-SATURATING,
GENERATED DECEMBER 1966, REFERENCES ARE
1, W A WITTKOPF, BAW-320, (DEC, 1966), GIVES DETAILS AND METHODS
2, J D GARRISON AND B W ROOS, NUCL SCI AND ENG 12, 115 (1962),
  OR GA-2112 (APRIL 1961), GIVES BASIC NUCLEAR DATA
3, N F WIKNER AND S JAYE, GA-2113 (JUNE 1961), GIVES NUCLEAR DATA

  THIS LUMPED FISSION PRODUCT IS USED IN A SCHEME WHERE THE TOTAL
FISSION PRODUCT POISON FROM A FISSIONABLE NUCLEUS IS REPRESENTED
BY THE FOLLOWING FIVE CHAINS OR FISSION PRODUCT GROUPS
     1, THE XE-135 CHAIN
     2, THE SM-149 CHAIN
     3, LFP1 (CD-113, SM-151, GD-155, GD-157)
     4, LFP2 (MO-95, TC-99, RH-103, XE-131, CS-133, ND-143,
              ND-145, PM-147, SM-152, EU-153)
     5, LFP3 (ALL OTHER FISSION PRODUCTS),

  CONVENTIONALLY, ONLY THE NEUTRON CAPTURE EVENTS ARE CONSIDERED
IMPORTANT FOR THE FISSION PRODUCT POISONS AND THEY ARE ASSUMED TO
BE INFINITELY DILUTE,  THUS, DATA IS SUPPLIED ONLY FOR MF=1,
MT=451 AND MF=3, MT=27
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ENDF/B MATERIAL NO= 1257

FISSION FRAGMENT RESIDUAL LUMP FOR PU-239
PUT IN ENDF/B2 FORMAT BY ZIZO LIVOLSI, BABCOCK=WILCOX, AUG 1971
THIS IS A FICTITIOUS NUCLIDE THAT INCLUDES INTO A SINGLE LUMP ALL
THE FISSION FRAGMENTS FROM PU-239 WITH EXCEPTION OF THE 53 NUCLI-
DES EXPLICITELY DESCRIBED IN ENDF/B, WALKER(1) HAS CALCULATED THE
SUM OF THE YIELD X SIGMA AND YIELD X RI, BY NORMALIZING THE SUM
OF YIELDS TO 2

AT 2200M	SIGMA-C	=	1.857	BARNS
ENDF DATA TOTAL CAPTURE INTEGRAL		=	14.59	BARNS

REFERENCES

1. WH WALKER, PRIV, COM, TO WA WITTKOPF (6/30/71)
2. FE LANE, AECL-3038(11/1969)

94-PU-240 1105 GGA.BNW PRI.COMM.CSEWG 1969 SEP69 MATHEWS.PITTERLE.LEONARD.PRINCE

```
                    ENDF/B MATERIAL NO= 1105
PU=240    CSEWG        EVAL=SEP69 MATHEWS,PITTERLE,LEONARD,PRINCE
                       DIST=JAN70 REV-APR-70
*         *            *        *        *        *
PLUTONIUM=240
          VARIOUS INDIVIDUALS CONTRIBUTED TO THE EVALUATION
          OF THE CROSS SECTIONS FOR THIS MATERIAL
          B,R,LEONARD(BNW)-  CROSS SECTIONS BELOW 0,5 EV
          T,A,PITTERLE AND H,YAMAMOTO(APDA)-  RESOLVED RES, PAR,
          D,R,MATHEWS(GGA)- UNRESOLVED RESONANCE PARAMETER AND
                    FAST ENERGY RANGE FISSION AND N,GAMMA X-SEC
                    PLUS OTHER NUCLEAR DATA
          A,PRINCE(BNL)-  TOTAL AND ALL SCATTERING CROSS SECTICNS
                    FCR NEUTRON ENERGIES ABOVE 40 KEV
          AND FISSILE AND FERTILE TASK FORCE (JUN-AUG,,1969)
*         *            *        *        *        *
BELOW 1,0 EV ALL X-SEC GIVEN FILE 3 (SMOOTH X-SEC)
BETWEEN 1,0 EV AND 3,9 KEV DATA GIVEN AS RESOLVED RESONANCE
PARAMETER PLUS A SMOOTH BACKGROUND GIVEN IN FILE 3
BETWEEN  3,9 KEV AND  40 KEV ALL DATA GIVEN IN FILE 2 (UNRESOLVED
RESONANCE PARAMETERS
*         *            *        *        *        *
          FILE 1      GENERAL INFORMATION
 MT=452   NU= 2,39 +  0,099*E    (REF,1,2)
 MT=453   (REF, 3)
*         *            *        *        *        *
          FILE 2      RESONANCE PARAMETERS
 RESOLVED PARAMETERS, FIRST TWO LEVELS (REF, 4), REMAINDER BASED
ON (REF, 5) WHICH WAS BASED ON (REF, 6,7,8,9,10),
 UNRESOLVED PARAMETERSBASED ON RECOMMENDED VALUES BY PITTERLE
 (REF, 5) FOR ENERGY RANGE FROM  3,9 TO 10 KEV,
 FROM 10 TO 40 KEV PARAMETERS BASED ON (REF, 5) WITH FISSION
 WIDTH ADJUSTED FOR PU-240 FISSION BASED ON U-235 FISSION
 GIVEN BY DAVEY (REF,11) AND PU-240 ALPHA FROM(REF,12)
*         *            *        *        *        *
          FILE 3      SMOOTH CROSS SECTIONS
BELOW 1,0 EV TOTAL AND ALL PARTIAL CROSS SECTIONS ADJUSTED
BY B,R,LEONARD (RER,4) TO BE CONSISTENT WITH 1969 IAEA EVAL
(REF, 13)
MT=18, 0,35 TO 3,91 KEV THESE DATA REPRESENT A CORRECTION TO
RESOLVED RESONANC REGION, PER REF, 5, TO ACCOUNT FOR MISSING
RESONANCES AND P-WAVE EFFECTS, 40 KEV TO 10 MEV IS FROM REF, 11,
10 TO 15 MEV IS BASED CN  U-235 FISSION OF REF, 14 AND A LINEAR
INTERPOLATION OF THE RATIO  (PU-240/U-235) THROUGH THE 14,1 POINT
OF REF 15,
MT=102    0,35 TO  3,91 KEV IS CORRECTION TO RESOLVED REGION PER
REF, 5 TO ACCOUT FOR MISSING RESONANCES AND P-WAVE EFFECTS,
MT=1,2,51,...91 CALCULATED BY A, PRINCE (REF,16) USING MODEL
CODES, JUPITOR AND ABACUS=NEARREX,
MT=16,17 FRON REF,12
MT=251,252,253 FROM FILE 4 DATA
*         *            *        *        *        *
          FILE 4      ANGULAR DISTRIBUTIONS
MT=2  CALCULATED BY PRINCE (REF,16)
MT=51,...,91 ASSUMED TC BE ISOTROPIC IN C.M.SYSTEM
*         *            *        *        *        *
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MT=15,16,91 MAXWELLIAN DISTRIBUTION (REF,12)
MT=18 SIMPLE FISSION SPECTRUM, T(E) = 0,50 + 0,43*(NU(E)+1,0)**5
USING FORMULA OF TERRELL (REF,17)

* * * * * *

REFERENCES

1, M,DE VROEY ET AL, JNE 20, 191 (1966),
2, B,D,KUZMINOV, SOVIET PROGRESS IN NEUTRON PHYSICS, 1961,
3, D,T,GOLDMAN, CHART OF NUCLIDES (9-TH ED, 1966),
4, B,R,LEONARD,JR,, PRIVATE COMMUNICATION TO CSEWG (AUG,1969)
5, T,A,PITTERLE AND H,YAMAMOTO, PRIVATE COMMUNICATION TO CSEWG, (A 1969 APDA EVAL, INCORPORATING THE GEEL DATA,JULY,1969),
6, M,G,CAO,ET AL, WASH,NEUT,CROSS SECT,CONF,(1968)
7, ,KALAS, ET AL, WASH,NEUT,CROSS SECT,CONF,(1968)
8, E,MIGNECO, ET AL, WASH,NEUT,CROSS SECT,CONF,(1968)
9, H,WEIGMAN, ET AL, WASH,NEUT,CROSS SECT,CONF,(1968)
10, M,ASGHAR, ET AL, PARIS CONF,ON NUCLEAR DATA FOR REACT,(1966)
11, W,G,DAVEY, NSE 32, 35 (1968)
12, T,A,PITTERLE AND M,YAMAMOTO, APDA-218/ENDF=122 (1968)
13, G,HANNA ET EA, AT, EN, REVIEW 7, NO4 (1969)
14, H,ALTER AND C,DUNFORD, AI-AEC-MEMO-12916 (JAN,1970)
15, D,H,WHITE AND G,P,WARNER, JNE 21, 671 (1967)
16, A,PRINCE, HELSINKI CONF,ON NUCL,DATA FOR REACTORS (JUNE,1970)

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94-PU-241 1106 BNL.AI PRI.COMM.1969 NOV69 E.OTTEWITTE AND A.PRINCE

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                     ENDF/B MATERIAL NO= 1106
PU-241     BNL + AI   EVAL-NOV69 E.OTTEWITTE AND A.PRINCE
                      DIST-JAN70 REV-JUN70
*          *          *          *          *          *          *
DATA MODIFIED MAY-1970
*          *          *          *          *          *          *
PLUTONIUM-241 FILE
THERMAL CROSS SECTIONS REVISED BY B. R. LEONARD
RESOLVED RES PMTRS EVALUATED BY J.R.SMITH.
UNRESOLVED RES REGION EVALUATED BY E.PENNINGTON AND E.OTTEWITTE.
MEV REGION EVALUATED BY A.PRINCE AND E.OTTEWITTE.
FILE ASSEMBLY BY E.OTTEWITTE.
MF=3 MT=51 EXCITION C/S FOR THE    40 KEV LEVEL
MF=3 MT=52 EXCITION C/S FOR THE    95 KEV LEVEL
MF=3 MT=53 EXCITION C/S FOR THE   163 KEV LEVEL
MF=3 MT=54 EXCITION C/S FOR THE   169 KEV LEVEL
MF=3 MT=55 EXCITION C/S FOR THE   174 KEV LEVEL
MF=3 MT=56 EXCITION C/S FOR THE   231 KEV LEVEL
MF=3 MT=57 EXCITION C/S FOR THE   245 KEV LEVEL
MF=3 MT=58 EXCITION C/S FOR THE   300 KEV LEVEL
MF=3 MT=59 EXCITION C/S FOR THE   335 KEV LEVEL
MF=3 MT=60 EXCITION C/S FOR THE   448 KEV LEVEL
MF=3 MT=61 EXCITION C/S FOR THE   753 KEV LEVEL
MF=3 MT=62 EXCITION C/S FOR THE   828 KEV LEVEL
MF=3 MT=63 EXCITION C/S FOR THE   894 KEV LEVEL
MF=3 MT=64 EXCITION C/S FOR THE   918 KEV LEVEL
MF=3 MT=65 EXCITION C/S FOR THE   941 KEV LEVEL
MF=3 MT=16 (N, 2N)                 (GA-6576) AND (AWRE O- 101/64)
MF=3 MT=17 (N, 3N)                 (GA-6576) AND (AWRE O- 101/64)
Q-VALUE REF R.HOWERTON ET AL,UCRL-14000(1964)
MF=5 MT=16  NUCLEAR TEMP FROM (AWRE 0-101/64)
MF=5 MT=17  NUCLEAR TEMP FROM (AWRE 0-101/64)
MF=5 MT=18  FISSION NEUTRON ENERGY DISTRIBUTION GIVEN
            AS SIMPLE FISSION SPECTRUM PLUS A
            MAXWELLIAN (AWRE 0-101/64)
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ENDF/B MATERIAL NO= 1258

FISSION FRAGMENT RESIDUAL LUMP FOR PU-241

PUT IN ENDF/B2 FORMAT BY EZIO LIVOLSI, BABCOCK-WILCOX, AUG 1971
THIS IS A FICTITIOUS NUCLIDE THAT INCLUDES INTO A SINGLE LUMP ALL
THE FISSION FRAGMENTS FROM PU-241 WITH EXCEPTION OF THE 53 NUCLI-
DES EXPLICITELY DESCRIBED IN ENDF/B. WALKER(1) HAS CALCULATED THE
SUM OF THE YIELD X SIGMA AND YIELD X RI, BY NORMALIZING THE SUM
OF YIELDS TO 2

AT 2200M	SIGMA-C	=	1.640	BARNS
ENDF DATA TOTAL CAPTURE INTEGRAL		=	16.85	BARNS

REFERENCES

1. WH WALKER, PRIV. COM. TO WA WITTKOPF (6/30/71)
2. FE LANE, AECL-3038(11/1969)

94-PU-242 1161 AI.ANC NAA-SR-12271(MAY67) AUG71 ALTER(AI) MOD.BY YOUNG+GRIMESEY

ENDF/B VERSION III EVALUATION OF THE RESOLVED RESONANCE AND THERMAL ENERGY CROSS SECTIONS OF ^{242}Pu - MAT 1161

T. E. Young and R. A. Grimesey

A new evaluation of the resolved resonance and thermal cross sections of ^{242}Pu below 390 eV has been made for Version III of ENDF/B based on new measurements. No changes were made to the Version II data above 390 eV.

The total neutron cross section below 1 eV was taken from References 1 and 2. The elastic scattering cross section at 0.0253 eV was calculated to be 8.4 b by using a potential scattering cross section of 10.7 b and the parameters of the 2.68 eV resonance only. A single bound level was selected which, when used in combination with the resolved resonances below 390 eV, also predicted a thermal scattering cross section of 8.4 b.

The total, absorption, and elastic scattering cross section values in Table I were calculated from the resonance parameters in Table II using the single-level formula and 10.7 b potential scattering. Parameters for resonances above 20 eV were obtained by averaging values from References 1 - 6, and those of the 2.68 eV resonance were taken from Reference 1.

Cross section values obtained at 0.0253 eV were 26.9 ± 1 b for the total, 18.5 ± 1 b for the absorption, and 8.4 ± 1 b for the scattering.

[1] T. E. Young, and S. D. Reeder, Nucl. Sci. Engr. 40, 389 (1970).

[2] T. E. Young. et al., Nucl. Sci. Engr. 43, 431 (1971).

[3] R. E. Côte, et al., Phys. Rev. 114, 505 (1959).

[4] P. A. Egelstaff, et al., J. Nuclear Energy, 6, 303 (1958).

[5] N. Pattenden, EANDC-50-S (1965).

[6] G. Anchampangh, et al., Phys. Rev. 146, 840 (1966).

Table I

Thermal Energy Region Cross Sections of Pu-242

Energy (eV)	σ_T (b)	σ_{abs} (b)	σ_{el} (b)
0.00001	960.	951.6	8.412
0.0001	297.	288.8	8.404
0.0005	139.	130.6	8.403
0.001	99.77	91.37	8.403
0.002	73.06	64.66	8.402
0.004	54.18	45.78	8.401
0.007	43.08	34.68	8.396
0.010	37.48	29.88	8.396
0.017	30.81	22.42	8.390
0.0253	26.87	18.48	8.383
0.040	23.23	14.86	8.370
0.060	20.66	12.31	8.353
0.080	19.15	10.82	8.335
0.10	18.14	9.821	8.318
0.15	16.60	8.3[illegible]5	8.272
0.20	15.72	7.4[illegible]3	8.225
0.30	14.75	6.624	8.125
0.45	14.10	6.135	7.961
0.60	13.86	6.083	7.776
0.80	13.91	6.418	7.489
0.90	14.06	6.735	7.324
1.00	14.30	7.157	7.143

Table II

Resonance Parameters of Pu-242

E_o (eV)	Γ_n^o (meV)	Γ_γ (meV)
-70.000	19.0000	25.600
2.680	1.2200	25.000
22.540	0.0632	25.600
40.930	0.0703	25.600
53.700	6.9320	25.600
68.000	0.5090	25.600
89.100	1.9180	25.600
106.000	0.0580	25.600
107.500	1.7260	25.600
131.800	0.5490	25.600
150.000	1.3880	25.600
166.000	0.0776	25.600
205.000	4.5750	25.600
217.000	0.3290	25.600
235.000	0.5150	25.600
276.000	0.8760	25.600
306.000	0.8750	25.600
311.000	0.6240	25.600
323.000	12.7420	25.600
335.000	5.1630	25.600
386.000	2.4070	25.600

95-AM-241 1056 ANC PRI.COMM.(NOV.66) NOV66 J.R.SMITH AND R.A.GRIMESEY

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                    ENDF/B MATERIAL NO= 1056
 AM-241     INC          EVAL=NOV66 J.R.SMITH AND R.A.GRIMESEY
 PRI.COMM.(NOV.1966)  DIST=JUL68 REV-JUN70
 *        *        *        *        *        *        *
 DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
 *        *        *        *        *        *        *
AMERICIUM 241 EVALUATED BY IDAHO NUCLEAR CORP NRTS
MF=1 MT=452 A WEIGHTED AVERAGE OF THE INDIVIDUAL DETERMINATIONS
            OF NU ASSIGNS MOST ALL WEIGHT TO THE V,I,LEBEDEV ET,AL
            ATOMNAYA ENERGIYA, 5 2 176 1958,VALUE, USING THE
            CURRENTLY FAVORED VALUE OF NU FOR 235 OF 2,43, WE
            OBTAIN NU=3,09 FOR THE CONSTANT TERM, THE SLOPE IS
            THAT OF THE UNIVERSAL CURVE OF J.C,HOPKINS AND B.C,
            DIVEN,NUC,PHYS, 48 433 1963,
     MT=453 DECAY DATA FROM D.T.GOLDMAN AND J.R,STEHN, CHART OF
            THE NUCLIDES, 1965,  WHEN BRANCHING OCCURS,
            ONLY THE MAJOR BRANCH IS FOLLOWED,
     MT=454 THE DATA OF J,G,CUNINGHAME,J.INORG,NUCL,CHEM, 4 7 1957
            AND R,R,RICHARD ET,AL, TRANS,AM,NUC,SOC, 6 2 1963,
            WERE PLOTTED AND A SMOOTH CURVE DRAWN THROUGH THE PTS,
            THE DATA WERE TAKEN FROM THE SMOOTH CURVE AND THE
            AUTHORS NORMALIZATION WAS ACCEPTED,
MF=2 MT=151 BELOW 16 EV THE DATA APPEARED TO BE ADEQUATELY
            REPRESENTED BY A FIT BY S,PEARLSTEIN,CROSS SECTIONS
            FOR TRANS-URANIUM ELEMENT PRODUCTION,BNL 982,1966,
            USING THE RECOMMENDED PARAMETERS FROM BNL 325 SUPP2,
            G=,5 POTENTIAL SCATTERING= 10 BARNS, SMOOTH CAPTURE
            CS IN RESOLVED AND UNRESOLVED RANGE IS 1/V AND IS
            417 BARNS AT ,0253 EV, SMOOTH FISSION CS IN RESOLVED
            RANGE ONLY IS 1/V AND IS 2,05 BARNS AT ,0253 EV,
            POINTWISE BOMB SHOT FISSION DATA USED THROUGHOUT
            UNRESOLVED RANGE TO ,1MEV AND CONSEQUENTLY NO FISSION
            WIDTHS SPECIFIED IN UNRESOLVED RANGE, UNRESOLVED
            CALCULATION IS FOR CAPTURE ONLY, AVERAGE NEUTRON WIDTH
            CALCULATED FOR ONE DEGREE OF FREEDOM IN PORTER THOMAS
            DISTRIBUTION,
MF=3 MT=  1 NO TOTAL CS MEASUREMENTS AVAILABLE ABOVE 16 EV, THE
            TOTAL CS WAS NOT ADDED DUE TO COMPLICATIONS WITH BOMB
            SHOT FISSION DATA, TOTAL CS IS SUM OF REACTION CS,
     MT=  2 BELOW ,1MEV ELASTIC CS IS 10 BARNS, ABOVE ,1MEV
            ELASTIC CS  IS THAT FOR PU 239,J.J,SCHMIDT EVALUATION
            KFK 120 KARLSRUHE,EXTRAPOLATED TO 15 MEV,
     MT=  4 NO DATA AVAILABLE, SINCE LEVEL STRUCTURE OF AM241 IS
            SOMEWHAT SIMILAR TO U238,WE USED U238 TOTAL INELASTIC
            CS TAKEN FROM J,J,SCHMIDT EVALUATION,KFK 120 KARLSRUHE
     MT= 18 IN THE THERMAL RANGE TO ,2EV A SMOOTH CURVE WAS
            DRAWN THROUGH THE EXPERIMENTAL POINTS IN BNL 325 SUPP2
            FROM 16 TO 20 EV DATA WAS TAKEN FROM G.D.BOWMAN
            (LRL,PVT,COM,), FROM 20 EV TO 0,4 MEV PETREL NUCLEAR
            EXPLOSION DATA ARE USED (P-3 AND W=8 STAFF, LASL 3586)
            FROM 20 EV TO 40 EV PETREL POINTWISE DATA ARE USED,
            FROM 40 EV TO 0.4 MEV 10 PERCENT AVERAGE DATA (P.A,
            SEEGER,PVT.COM.) ARE USED, ABOVE 0,4 MEV DATA ARE FROM
            SMOOTH CURVE DRAWN THROUGH PETREL DATA (TO 2 MEV) AND
            DATA OF NOBLES ET AL (PHYS,REV,99,616A (1955)), NORM,
            AT PLATEAU (2-4 MEV) TO 1,75B, WHICH IS WTD, AVE, OF
            VALUES FROM SEEGER (PETREL), NOBLES, BOWMAN (IAEA CONF
            PARIS CN-23/18 1966), KAZARINOVA (AT,ENERG,USSR 8 139
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                1960) 15 MEV VALUE IS AVE. BETWEEN KAZARINOVA AND
                PROTOPOPOV (AT.ENERG.USSR 6 67 1959).
      W-VALUE REF.A.PRINCE,PRIVATE COMMUNICATION 23APR68
          MT=102 POINTS FROM 0.001EV TO 0.2 EV ARE FROM SMOOTH CURVE
                DRAWN THROUGH DATA OF ADAMCHUK ET AL (PROC.INT CONF ON
                PUAE /P/645 1955), WITH 10 B. POT. SCAT. SUBTRACTED TO
                OBTAIN ABS. CS. THE FISSION CS WAS THEN SUBTRACTED TOO
                OBTAIN CAPTURE CS. BETWEEN .2 AND .3 EV THE SMOOTH
                CAPTURE FILE REPRESENTS THE DIFFERENCE BETWEEN THE
                PEARLSTEIN FIT (NBL 982) AND A SMOOTH CURVE THROUGH
                THE EXPERIMENTAL POINTS OF SLAUGHTER (ORNL 3085) AND
                ADUMCHUK.
                .3EV TO.1MEV THE SMOOTH CAPTURE CS IS 1/U WITH A VALUE
                OF 417 BARNS AT.0253EV. AN UNRESOLVED CALC. USING THE
                PARAMETERS IN FILE 2 YIELDED A VALUE OF .43 BARNS AT
                .1MEV. THIS ADDED TO THE RESIDUAL 1/V SMOOTH CAPTURE
                CS GAVE A VALUE OF .64 BARNS CAPTURE AT .1MEV. A
                STRAIGHT LINE WAS DRAWN FROM .64 BARNS AT .1MEV TO
                THE OPTICAL MODEL VALUE OF D.T.GOLDMAN,TRANS.AM.NUCL.
                SOC. 7 84 1964. AT .6 MEV FOR NP237. THE CAPTURE CS
                VALUE USED FROM HERE TO 10 MEV IS BASED ON AN
                EXTRAPOLATION OF THE GOLDMAN CURVE FOR NP237.
        MT=251,252,253 MU-BAR(L-SYSTEM),XI,GAMMA CALCULATED BY CHAD
    MF=4 MT=  2 ANGULAR DISTRIBUTIONS SUPPLIED BY H.ALTER OF AI; COMP-
                OSED OF A MIXTURE OF MEASURED DATA FOR U235,U238,AND
                PU239. VALUES OF GAMMA SLOWING DOWN PARAMETER ABOVE
                10 KEV ARE SUSPECT AND ARE NOT TO BE USED WITHOUT
                FUTHER STUDY.
    MF=5 MT=  4 EVAPORATION MODEL SPECIFIED FOR INELASTIC CS. TEMP
                CALCULATED FROM 3230 SQUARR RT(E/A). NO LEVEL DATA
                AVAILABLE.
         MT=18  FISSION SPECTRUM HAS MAXWELLIAN DENSITY WITH THE TEMP
                BASED ON  TERRELLS PRESCRIPTION (TERRELL.J..PHYSICS
                AND CHEMISTRY OF FISSION,VOL 2..IAEA,1965).THE THERM
                VALUE OF NU WAS USED TO DETERMIN THE TEMPERATURE.
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95-AM-243 1057 ANC PRI.COMM.(NOV.66) NOV66 J.R.SMITH AND R.A.GRIMESEY

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                     ENDF/B MATERIAL NO= 1057
 AM-243     INC          EVAL=NOV66 J.R.SMITH AND R.A.GRIMESEY
 PRI.COMM.(NOV,1966)  DIST=JUL68 REV-JUN70
 *          *           *          *          *          *          *
 DATA MODIFIED JUNE,1970 TO CONFORM TO ENDF/B-II FORMATS
 *          *           *          *          *          *          *
AMERICIUM 243 EVALUATED BY IDAHO NUCLEAR CORP NRTS
MF=1 MT=452 THE CONSTANT TERM WAS PURE GUESS,THE SLOPE IS BASED ON
            THE UNIVERSAL CURVE OF J.C.HOPKINS AND B.C.DIVEN,
            NUC.PHYS. 48 433 1963.
     MT=453 DECAY DATA FROM D.T.GOLDMAN AND J.R.STEHN, CHART OF
            THE NUCLIDES, 1965.  WHEN BRANCHING OCCURS,
            ONLY THE MAJOR BRANCH IS FOLLOWED.
     MT=454 NO YIELD DATA, USED AM 241 YIELD CURVE.
MF=2 MT=151 RES PARAMS BASED ON FIT OF S.PEARLSTEIN,CROSS SECTIONS
            FOR TRANSURANIUM ELEMENT PRODUCTION,BNL 982 1966.
            G=.5,POTENTIAL SCATTERING CS IS 10 BARNS,NO 1/V
            SMOOTH CAPTURE NECESSARY, RESOLVED RES RANGE EXTENDS
            INTO THERMAL REGION TO .0001 EV, NO DATA EXCEPT
            FISSION ABOVE 16 EV THEREFORE EXTENDED UNRESOLVED
            RANGE TO 10000 EV,UNRESOLVED PARAMETERS AVERAGED FOR
            S WAVE NEUTRONS ONLY BASED ON PEARLSTEIN RESOLVED
            PARAMETERS, UNRESOLVED RES CALCULATION USING THESE
            PARAMETERS GAVE A CAPTURE CS AT 10KEV OF 1.493 BARNS
MF=3 MT=  1 TOTAL CS IS SUM OF MT=2,4,18,102 NO MEASUREMENTS ABOVE
            16 EV
     MT=  2 RESONANCE RANGE BELOW 10KEV,FROM 10KEV TO .1 MEV
            SET ELASTIC TO 10 BARN POTENTIAL SCATT CS, ABOVE .1
            MEV DATA IS THAT FOR PU239 J.J. SCHMIDT EVALUATION,
            KFK 120 KARLSRUHE,EXTRAPOLATED TO 15 MEV.
     MT=  4 NO DATA AVAILABLE, SINCE LEVEL STRUCTURE OF AM 243 IS
            SIMILAR TO U238,WE USED U238 TOTAL INELASTIC CS FROM
            J.J.SCHMIDT EVALUATION KARLSRUHE.
     MT= 18 ABOVE 10000 EV USED SMOOTH LINE THROUGH D.K.BUTLER AND
            R.K.SJOBLOM DATA IN BNL 325 SUPP2, EXTRAPOLATED FIRST
            D.K.BUTLER POINT AT .30 MEV TO .001 BARN AT 10000 EV.
     MT=102 SMOOTH CAPTURE CS IS 0.0 BELOW 10KEV, AT 10KEV CAPTURE
            CS BASED ON 1.493 BARN UNRESOLVED CS AT 10KEV. THIS
            POINT IS EXTRAPOLATED LINEARLY TO POINT ON D.T.GOLDMAN
            TRANS.AM.NUCL.SOC. 7 84 1964,CURVE AT .3MEV FOR NP237.
            ABOVE .3 MEV CAPTURE CS FOLLOWS D.T.GOLDMAN CURVE
            FOR NP237 EXTRAPOLATED TO .001BARN AT 10MEV.
   MT=251,252,253 MU-BAR(L-SYSTEM),XI,GAMMA CALCULATED BY CHAD
MF=4 MT=  2 ANGULAR DISTRIBUTIONS SUPPLIED BY H.ALTER OF AI;
            COMPOSED OF A MIXTURE OF MEASURED DATA FOR U235;U238,
            AND PU239. VALUES OF GAMMA SLOWING DOWN PARAMETER
            ABOVE 10KEV ARE SUSPECT AND ARE NOT TO BE USED WITHOUT
            STUDY.
MF=5 MT=  4 EVAPORATION MODEL SPECIFIED FOR INELASTIC CS,TEMP
            CALCULATED FROM 3230SQUARE RT(E/A). NO LEVEL DATA
            AVAILABLE.
     MT=18  FISSION SPECTRUM HAS MAXWELLIAN DENSITY WITH THE TEMP
            BASED ON TERRELLS PRESCRIPTION (TERRELL,J.,PHYSICS
            AND CHEMISTRY OF FISSION,VOL 2, IAEA,1965). THE THERM
            VALUE OF NU WAS USED TO DETERMINE THE TEMPERATURE
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ENDF/B VERSION III EVALUATION OF THE RESOLVED RESONANCE AND THERMAL ENERGY CROSS SECTIONS OF ^{244}Cm - MAT 1162

J. R. Berreth and R. A. Grimesey

A new evaluation of the resonance and thermal cross sections of ^{244}Cm below 500 eV has been made for Version III of ENDF/B based on new measurements[1,2,3] both at low energies and in the resolved resonance region.

These measurements bring up to date the low energy evaluation of ^{244}Cm based on direct low energy measurements and new and additional determinations of resonance parameters. New resonance parameters are presented up to 500 eV (see Table I). Low energy resonances up to and including 85.8 eV are a composite of three sets of data, Coté et al.[1], M. S. Moore et al.[2], and J. R. Berreth and F. B. Simpson[3]. The data of Berreth and Coté are total neturon cross sections. The Moore data are capture and fission cross section measurements. The fission component for the 16.8 eV resonance is an indirect determination by Moore based on comparing their capture and fission measurements. The energy of this resonance is at the lower energy range of their measurements and, therefore, subject to some error in the fission parameters. Since no fission measurement was available, a fission component for the 7.66 eV resonance was used based on the average fission parameters of several large low energy resonances. Because the resonance parameters do not account for all of the low energy cross section as measured, a negative energy resonance is postulated to make up the difference between the theoretical curve as determined from the resonance parameters and the measured data below 1 eV. Conditions for postulating the negative energy resonance were as follows: all of the measured resonances to 500 eV were reflected as bound states around the 7.66 eV resonance in order to arrive at a scattering cross section. Parameters for an assumed negative energy resonance at -1.48 eV were then adjusted until a fit to the total cross section data between 0.01 and 1.0 eV was achieved. The revised cross sections determined from the above information at 0.0253 eV are σ_{tot} = 23.56 barns, σ_{sc} = 8.40 barns, $\sigma_{n\gamma}$ = 14.28 barns, and σ_{fiss} = 0.88 barns. These total neutron cross sections data have been determined using the single-level Breit-Wigner formula.

In addition to these modifications, the average fission width $\langle\Gamma_F\rangle$ for the unresolved range was re-determined by averaging the resolved range fission widths based on M. S. Moore[2] data. This was the only adjustment made to the unresolved range data.

Below 3.0 eV the File 3 data gave the complete cross sections. The elastic cross section is based on the contribution of postulated bound levels obtained by reflecting all of the positive energy resonances to the negative axis to approximate bound levels in addition to the resonances given in File 2. At 3 eV, the difference between the elastic cross section involving these bound levels and the cross section obtained from the resonances in File 2 is 1.334 barns. Above 3 eV, File 3 contains this cross section at 3 eV extrapolated linearly to zero at 1.50 eV as an approximation to bound levels not present in File 2. The difference between the capture and fission cross section, fit as described above, is a 1/v cross section above 3.0 eV given in File 3.

In these calculations the potential scattering cross section was taken to be 10.32 barns.

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[1] R. E. Coté, R. B. Barnes and H. Diamond, "Total Neutron Cross Section of ^{244}Cm", Phys. Rev. Vol. 134, No. 6B, pp. 1281-1284 (June 22, 1964).

[2] M. S. Moore and G. A. Keyworth, "Analysis of the Fission and Capture Cross Sections of the Curium Isotopes", Phys. Rev. C, Vol. 3, No. 4 pp. 1656-1667 (April 1971).

[3] J. R. Berreth and F. B. Simpson, "Total Neutron Cross Sections of the Cm Isotopes from 0.01 to 30 eV", (to be published).

^{244}Cm RESONANCE PARAMETERS USED FOR ENDF/B REVISION

Energy eV	$2g\Gamma_n^0$ mV	Γ_γ mV	Γ_f mV
-1.480	0.0685	37.000	2.100
7.660	3.5700	37.000	2.100
16.800	0.4000	37.000	1.400
22.864	0.1840	37.000	3.700
34.900	0.5900	37.000	2.500
52.670	0.0780	37.000	1.700
69.900	0.0720	37.000	3.000
85.800	0.3900	37.000	0.650
96.120	0.7450	37.000	1.540
132.800	1.3500	37.000	1.170
139.100	0.2120	37.000	2.800
171.200	0.2360	37.000	1.300
181.600	0.7240	37.000	2.100
197.000	3.0600	37.000	1.000
209.800	2.9000	37.000	0.520
220.100	3.6400	37.000	1.250
230.500	1.9800	37.000	0.400
234.900	0.2500	37.000	0.900
242.700	0.0830	37.000	2.200
264.900	0.6150	37.000	0.900
274.100	0.9670	37.000	0.800
316.800	0.3090	37.000	0.300
329.500	0.3630	37.000	0.290
343.600	1.4000	37.000	1.160
353.100	5.3800	37.000	1.280
361.700	1.7900	37.000	1.030
364.400	0.5240	37.000	2.100
386.200	1.3200	37.000	1.110
397.600	1.1500	37.000	0.660
415.000	0.9300	37.000	0.270
420.600	4.5400	37.000	0.890
426.900	0.6200	37.000	0.350
443.400	4.8000	37.000	0.820
470.900	7.6900	37.000	1.840
488.900	0.6780	37.000	0.500
491.900	2.4300	37.000	0.470